Swine Research Program

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U.S. Meat Animal Research Center

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ROMAN L. HRUSKA U.S. MEAT ANIMAL RESEARCH CENTER[1]

Overview on the Center

The Roman L. Hruska U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964, creating a single facility that provides an unusual opportunity for making major contributions to the solution of problems facing the U.S. livestock industry. Development of the 35,000-acre facility started in the spring of 1966 and is continuing at the present time. Phase I construction, consisting of an office-laboratory building for intensive investigations, was completed in January 1971. These facilities provide a physical plant for 42 scientists and about 200 support personnel. Phase II construction, consisting of the Meats Research Laboratory and Agricultural Engineering Building, was completed in October 1977. It provides a physical plant for 25 scientists and about 60 support personnel. Phase III construction will provide facilities for a comprehensive research program of producing, harvesting, handling, storing, and using forages in livestock production systems. Approximately 35 additional scientists and 65 support personnel will be required for this phase. Currently, one-third of the scientific staffing is completed.

Approximately one-half of the research program is devoted to beef cattle, one-fourth to sheep, and one-fourth to swine. Current research program objectives require breeding-age female populations of approximately 7,000 cattle (20 breeds and crossbreds), 5,000 sheep (9 breeds and crossbreds), and 550 swine litters per year (8 breeds and crossbreds).

The research program at the Center is organized on a multidisciplinary basis and is directed toward extending investigations into new areas not now being adequately studied to provide new technology to increase quantities of palatable, wholesome, and nutritious meat. We are planning and conducting from the basic cellular level, examining the very fundamental biology of life processes to the animal level, and examining environmental and genetic influences on meat quantity, composition, and quality. The aim of the research program is to provide basic knowledge of the fundamental processes of biology as a basis for developing new technology with production and consumer application.

The current program includes research in genetics and breeding, nutrition, reproduction, agricultural engineering, meats, production systems, and crop residue-forage utilization. The research program complements research conducted elsewhere by the U.S. Department of Agriculture (USDA) and is cooperative with the Nebraska Agricultural Experiment Station and other land grant university agricultural experiment stations throughout the country. The program is also designed to complement existing domestic and international research programs in developing livestock production technology.

[1]Agricultural Research Service, U.S. Department of Agriculture, the University of Nebraska, and other cooperating land grant universities.

Overview on the Swine Research Program

MARC's swine research program places the highest priority on developing technology capable of having an immediate and major impact on the swine industry. Although the program is largely oriented towards fundamental research, emphasis is placed on the generation of technology that can be practically implemented by small farmers and commercial swine producers alike within a relatively short time frame.

Currently, we have 10 scientist "equivalents" conducting research in the swine program at MARC. They are working in 8 primary thrust areas and have 27 experiments under way. In addition, they are coworkers on three major projects away from MARC. Also, MARC has an active predoctoral, postdoctoral, and visiting scientist program, which supports the swine research program.

This report represents a cross section of our swine research program at the present time. Since some of the projects from which results are reported are still in progress, the preliminary nature of some of the results must be recognized. However, it is our opinion that information useful to the industry should be provided at the earliest possible time. Progress reports of this nature will be released periodically to make current results available to the industry. For convenience, the research program is reviewed on a discipline basis in this report with problem areas listed under the disciplinary unit that is taking the lead on research programs in each specific problem area.

Robert R. Oltjen, Director
Roman L. Hruska U.S. Meat
Animal Research Center

Crossbreeding Evaluation of Long-Term Selection for High- and Low-Backfat and for Industry Goals in Duroc and Yorkshire Swine

Gordon E. Dickerson, Howard S. Teague, and Larry D. Young[1]

Introduction

Lines of pigs sampled from the Duroc and Yorkshire breeds in the mid-1950's were selected for high- or for low-backfat thickness for 18 and 16 generations, respectively, by H. O. Hetzer at the Beltsville Agricultural Research Center, U.S. Department of Agriculture (USDA), Beltsville, Md. Responses in pure line performance relative to unselected control lines of each breed have been reported in other publications. Because of relatively small numbers of breeders per line, however, cumulative inbreeding reached levels of 35 to 40 percent in the selected and 30 to 34 percent in the control lines. Some information on performance of these lines in crosses had been reported for preweaning traits but not for postweaning growth, carcass traits, or for the female reproductive traits most affected by inbreeding.

These long-selected high- and low-backfat and unselected control lines of two breeds provided unique opportunity to (1) evaluate cumulative responses in all components of performance of Duroc x Yorkshire crosses within each type of selection, free of bias from inbreeding effects; (2) estimate parallel change in performance from industry selection in the Duroc and Yorkshire breeds; and (3) determine effects of large genetic differences in body composition on utilization of feed energy for fat or lean deposition.

Procedure

Samples of a boar or gilt were taken from each of 10 to 12, 1971 fall litters of each of the six Beltsville lines (high-fat, low-fat and unselected lines in both Duroc and Yorkshire breeds). Matings in isolation at the Roman L. Hruska U.S. Meat Animal Research Center (MARC) were used to produce 41 pure-line litters taken by hysterectomy in 1973. During the same period, hysterectomy litters were obtained from 12 purebred Duroc sows and 5 boars, representing 6 outside herds, and from 11 purebred Yorkshire sows and 4 boars representing 4 outside herds. Eight Hampshire hysterectomy litters by three boars representing two breeders also were obtained.

Table 1 illustrates the crosses made between Duroc and Yorkshire lines to compare cumulative effects on crossbred performance from selection for high-fat (H), low-fat (L), or purebred (P) goals as deviations from unselected controls (U). Sampling of lines fell below intended numbers of crossbred litters of 30 each for P and U and 20 each for L and H lines because of poor fertility in L and especially in P and H matings, even though inbreeding averaged 36 percent in L and 42 percent in H breeders and zero in P, compared with 30 percent in the U breeders. Retention of six H boar pigs for breeding further limited number of H barrows.

All crossbred gilt pigs were retained for evaluation of reproductive performance in first and second parity matings with Hampshire boars.

Results

Growth and feed efficiency of Duroc x Yorkshire crossbred pigs (Table 2) shows that high-fat selection reduced birth weight 17 percent but increased weaning weight a little and reduced postweaning gain, feed consumption, and feed efficiency only slightly. Low-fat selection increased birth weight 12 percent without changing weaning weight but reduced postweaning gain less than feed consumption and, thus, maintained feed/gain. Purebred selection since the 1954 base period increased prenatal growth rate 18 percent and also increased growth from birth to 24 weeks more than feed intake, thus reducing feed/gain a little.

Body conformation and composition were greatly affected by the different long-term selection programs (Table 3). High-fat selection reduced both body and leg length at 220-lb liveweight, reduced muscling score 48 percent and loin eye area 22 percent, and increased backfat 48 percent. Low-fat selection increased both

Table 1.—Mating plan for comparison of Duroc x Yorkshire crossbreds from long-term high-fat (H), low-fat (L), and industry purebred (P) selection with those from unselected control (U) lines of both breeds

Foundation			Reciprocal cross	Hamp. ♂ x D-Y ♀
Jan.-Sept. 1973 (No. SPF litters)			June-July, Nov.-Dec. 1974 (No. litters – ♂ – ♀ at 8 mo.)	1975 through July 1976 (No. 1st and 2nd litters)
High fat	8 Duroc	(DH)		
			11 – 13 – 27	30
	5 York	(YH)		
Control	7 Duroc	(DU)		
			30 – 80 – 79	120
	6 York	(YU)		
Low fat	7 Duroc	(DL)		
			21 – 63 – 67	60
	8 York	(YL)		
Purebred	12 Duroc	(DP)		
			27 – 60 – 57	70
	11 York	(YP)		
Total	64		89 – 216 – 230	280

Table 2.—Changes in growth and feed use of Duroc x Yorkshire barrows from long-term selection for high– (H) and low– (L) backfat and in purebred herds (P), relative to unselected controls (U)

Trait	Mean	Percentage change		
	U	H	L	P
No. pigs at birth (24 wk)----------	244 (159)	75 (40)	183 (130)	215 (117)
Birth weight ----------lb---	2.3	–16.9	11.7	18.2
Weaning (8 wk) weight----------lb---	32.2	12.4	1.2	14.9
24-wk weight ----------lb---	196.4	–4.0	–7.6	11.0
Age at 220 lb ----------days---	185.0	3.8	9.2	–7.0
From 45 to 220 lb:				
Gain/day----------lb---	1.47	–6.8	–10.2	9.5
Feed/day ----------lb---	4.3	–2.6	–11.8	5.3
Feed/100 lb gain----------lb---	297.0	5.1	–4.4	–5.1

[1]Dickerson and Young are research geneticists, Genetics and Breeding Unit, MARC, and Teague, formerly a research chemist, Nutrition Unit, MARC, is now a nonruminant nutritionist, Cooperative State Research Service.

body and leg length and loin eye 30 percent and reduced backfat 25 to 40 percent but not the visual score for muscling. Purebred breed selection also increased body length slightly and loin eye by 26 percent but reduced backfat only 22 to 28 percent, left leg length unchanged, and increased visual score for muscling 28 percent.

Changes in lean content were strongly negative for H selection, but strongly positive for L and P selection, as indicated by yield of separable lean in ham and loin. Low-fat and P selection both excelled in loin lean, and P exceeded the L in ham lean, as might be expected from selection on backfat probe in L vs that on visual appearance of (ham) muscling for P selection. Ranking of stocks for chemical composition of untrimmed 10th rib chop agreed with that for separable lean of loin except that chemical fat was not reduced as much in P as in the L crosses. Also, fat content of loin muscle was actually greater in P and lower in L crosses.

Pork quality, as measured in the loin muscle, was improved in the H and reduced some in the P and L crosses. High-fat crosses were improved in water-holding capacity (light transmission), marbling, and tenderness. Both the L and P crosses were poorer in tenderness and water-holding capacity, but the L improved in color and P improved in marbling.

Feed conversion to body protein and fat is presented in Table 4. The change in fat content from unselected controls was about 37 percent in H, –33 percent in L, and –21 percent in P crosses, arising from slower protein but faster fat deposition in H and the reverse in L and P crosses. Daily feed intake declined very little in H, but –12 percent in L, and increased slightly in P crosses.

Comparative use of feed intake from 46- to 220-lb liveweight (Table 4) was based on the known energy content of fat and protein (9.5 and 5.7 Kcal/g) and total above-maintenance energy cost of fat or protein deposition (13 Kcal/g). At the same average liveweight, feed energy used for maintenance relative to controls was 45 percent less for H compared with about 30 percent more for L and P crosses, roughly proportional to the changes in lean mass. Total energy loss (maintenance plus synthesis of protein and fat) decreased 22 percent in H and increased 18 percent in P but only 7 percent in L pigs. Partition of feed energy intake then involved a very large increase for maintenance and protein deposition and a large decrease for fat deposition by P and L crosses and the reverse for H crosses. Change in liveweight gain/lb of feed was

Table 3.—Changes in carcass traits of Duroc x Yorkshire barrows at 220 lb liveweight from long-term selection for high– (H) and low– (L) backfat and in purebred herds (P) relative to unselected controls (U)

Trait	Mean	Percentage change		
	U	H	L	P
No. pigs	90	13	48	58
Measurements:				
Body length, in	29.3	–6.9	5.1	3.8
Leg length, in	19.7	–8.2	5.8	1.4
Muscling score (1-5)	3.28	–47.9	2.1	28.4
Backfat, 3 midline, in	1.96	47.9	–24.5	–21.9
Backfat, 4 over loin, in	1.88	47.2	–39.9	–28.2
Loin eye area, in^2	3.58	–21.7	30.0	26.1
Yields, percent of liveweight:				
Dressing	72.8	–.3	–2.9	.5
Ham, skinned, trim	10.9	–25.7	18.3	25.7
Ham, boneless, defatted	9.1	–25.3	18.7	25.3
Loin, trimmed chops	12.6	–17.5	17.5	17.5
Loin, separable lean (est.)	10.2	–8.6	14.2	13.5
Ham plus loin, separable lean	19.3	–16.5	16.3	19.0
Composition, untrimmed 10th rib chop (pct):				
Separable lean	42.7	–17.6	30.0	19.0
Separable fat	44.2	27.6	–36.7	–24.9
Soft tissue, water	28.6	–36.7	47.6	29.7
Soft tissue, protein	8.2	–48.0	58.4	36.3
Soft tissue, fat	63.0	22.0	–28.9	–17.8
Loin muscle, water	73.5	–2.7	.1	–.7
Loin muscle, protein	22.5	–3.6	.9	–1.3
Loin muscle, fat	2.5	110.6	–9.4	42.5
Muscle quality:				
Light transmission (–)	8.7	17.2	–100.0	–64.4
Warner-Bratzler shear (–), lb/in^2	41.3	21.6	–6.5	–4.5
Marbling (1-5)	2.4	60.0	–1.2	36.2
Color (1-5)	2.88	–.3	10.4	–5.9

Table 4.—Estimated empty body composition, daily gain, and feed energy use from 45 to 220 lb liveweight for high-fat (H), low-fat (L), and purebred (P) crossbred barrows, relative to unselected controls (U)

Trait	Mean	Percentage change		
	U	H	L	P
Empty body:[1]				
Percent protein	10.44	–37.6	33.1	21.4
Percent fat	44.4	36.5	–32.9	–21.2
Protein gain/d, lb	.146	–42.0	19.9	32.6
Fat gain/d, lb	.621	27.2	–39.7	–13.9
Feed energy, Kcal/d, percent:				
Intake	6314 (100)	–2.6	–11.8	5.3
Maintenance	1793 (28)	–44.7	29.8	31.5
In body protein	377 (6)	–41.9	20.2	32.9
In body fat	2664 (42)	27.2	–39.7	–13.9
Synthesis of protein, fat	1480 (24)	4.6	–20.2	1.3
Total heat loss	3273 (70)	–22.4	7.2	17.8
Partition of feed ME/d, percent:				
Maintenance	28.4	–43.0	47.0	25.0
Protein deposition, total	13.6	–40.0	36.0	26.0
Protein deposition, edible	9.3	–45.0	39.0	32.0
Fat deposition	58.0	31.0	–32.0	–18.0
Weight gain/feed, percent:				
Shrunk liveweight	32.1	–4.0	2.0	4.0
Protein, total	3.36	–40.0	36.0	26.0
Protein, edible	2.29	–45.0	39.0	32.0
Fat	18.65	31.0	–32.0	–18.0
Total ham + loin lean/lb of pig feed, percent	5.2	–20.0	19.0	24.0

[1]Empty body protein and fat were estimated from the separable lean and fat in ham and loin and chemical composition of untrimmed loin chops.

negligible, but change in protein or fat gain/feed changed dramatically to –40 or 31 percent for H, 36 or –32 percent for L, and 26 or –18 percent for P crosses. Thus, usefulness of changing body composition depends primarily upon the relative value/unit of pork lean vs fat output.

Effects on sow performance from long-term selection for high- or low-backfat or for P goals are shown in Table 5. All crossbred gilts were checked for estrus with boars beginning at about 4 months of age and mated with Hampshire boars to farrow two litters at about 12 and 18 months of age in June to February and in November to June. First estrus was detected nearly 3 weeks later in H and P crosses than in control and L gilts, but rebreeding interval was more than 2 weeks longer for L and P than for control or H sows.

No sure evidence was found for changes in fertility from the different selection programs (Table 5) although fertility observed was lower for H and L than for control crossbred females. Effects of selection on litter size were small enough to suggest only some loss in number born and weaned from P selection and loss in number born but better preweaning survival from H selection. At essentially the same ages, sow weights before first and second farrowings were reduced by H selection but increased by P selection and unchanged by L selection. The H sows lost only about one-fourth as much weight as others between farrowing and weaning even though survival of their pigs was better.

Total litter weight born was reduced by H and increased by both L and P selection because of the very real changes in pig birth weights; however, changes in either litter weight or pig weight weaned were too variable for the relatively small numbers sampled to indicate a real trend. Gestation length was slightly, but consistently, shorter in H and longer in L and P crosses. Also, number of nipples was increased especially from L and P selection of dams, in agreement with early observations on the crossbred dams themselves.

Net gains from two decades of selection were estimated to be nearly one-fourth more lean pork marketed at 220-lb liveweight for each lb of feed in crossbred pigs from industry purebred samples of Duroc and Yorkshire and one-fifth more in crosses of lines especially selected only for thinner backfat. Purebred selection also increased sow size and delayed sexual maturity and may have reduced litter size, partly offsetting gains in lean growth efficiency of market pigs. Low-backfat selection did not increase sow size, delay sexual maturity, nor reduce litter size, but maintenance requirements may have increased for the leaner sows. High-backfat selection reduced lean pork/lb of feed about one-fifth for market pigs, did not reduce reproductive performance, and did reduce sow size and maintenance requirements. High-fat selection would be beneficial only if it were desirable to maximize efficiency of converting feed energy to pork fat.

Table 5.—Reproductive performance for first 2 parities of high-fat (H), low-fat (L), and purebred (P) crossbred gilts, relative to unselected control (U) gilts

	Mean	Percentage change		
Trait	U	H	L	P
Age at 1st estrus----------days---	193	10	–3	8
Days, 1st farrow to 1st estrus----------	52.0	–4.0	29.0	33.0
No. nipples at 6 wk----------	12.2	5.0	6.0	12.0
No. females assigned:	173	41	94	93
Bred/assigned ----------percent---	85.0	–4.0	4.0	–2.0
Farrowed/bred ----------percent---	83.0	–13.0	–13.0	1.0
Farrowed/assigned ---------percent---	71.0	–14.0	–10.0	–3.0
No. with 1st/2nd litters:	79/46	17/10	44/23	39/24
Interval 1st to 2nd litter---------days---	185	–1	4	2
Age at 1st/2nd farrow----------days---	376/562	–4/–1	1/2	2/3
Weight before 1st/2nd farrow------lb---	337/388	–18/23	3/–2	18/12
Weight after 1st/2nd weaning -----lb---	287/326	–8/–14	–2/2	12/16
Gestation length----------days---	112.7	–.4	.5	.8
Litter size born/weaned----------	10.2/8.4	–8/6	0/1	–4/–7
Litter weight born live/weaned ----lb---	27.8/115	–19/–13	11/–1	13/–6
No. pigs born:	1251	232	733	617
Birth weight----------lb---	2.7	–17.0	10.0	17.0
Survival to weaning---------percent---	82.0	17.0	1.0	–4.0
Weaning (4 wk) weight----------lb---	13.8	–19.0	–3.0	1.0
Nipple number at 4 wk ----------	12.9	2.0	4.0	5.0

Bioeconomic Model To Simulate Effects of Genetic Changes in Performance on Life-Cycle Efficiency of Pork Production

Michael W. Tess, Gary L. Bennett, and Gordon E. Dickerson[1]

Introduction

Methods for evaluating breeding stock and for changing breeding values of one or more traits in a population have been improved considerably in recent decades; however, relatively little attention has been focused on the definition of selection objectives. Animal breeders must determine which biological components offer greatest opportunity for genetic improvement in net cost/unit of output or efficiency of production.

The objective of the research described here was to construct a bioeconomic computer model of life-cycle pork production capable of simulating the effects of genetic changes in performance traits on several measures of production efficiency. This work represents an attempt to interpret and utilize experimental results in nutrition, genetics, physiology, meats, and economics to answer questions beyond the scope of animal experimentation.

Procedure

The approach used in constructing the model was to account as accurately as possible for the biological and economic inputs needed to sustain a predetermined level of performance. Feed and nonfeed inputs were treated as dependent variables determined by genetic levels for the various performance traits. Base levels of performance were chosen to be representative of modern crossbred hogs raised in a farrow-to-finish production unit. Production costs represented those for midwestern, environmentally regulated, slotted-floored farrowing and nursery units, and modified-open-front finishing buildings. Economic assumptions were based upon 1980 prices.

The primary controlling variables used by the model were genetic means for age at puberty, conception rate, litter size at birth, pig viability, lean growth rate, and fat growth rate. Genetic changes simulated for each trait included associated changes expected in other traits without a change in their breeding values.

A limited number of management options were also included in the model such as maximum number of farrowings/sow, age at weaning, age when first exposed to a boar, and time allowed for rebreeding after a sow weans her litter. Pigs could be marketed either at a constant weight or at the mean weight for a constant age.

Production outputs for the model included both pigs and culled sows, either as liveweight or as carcass lean. Outputs from sows were discounted in value relative to market pigs.

Primary sources for information used in the computer simulation model were experimental results from scientific literature and cost accounting studies.

Results

The baseline levels of performance for sows and pigs (Table 1) were considered representative of those obtainable under modern production conditions. These results include the simulated effects of parity number and sex upon various measures of performance. Weight gains, feed/gain ratios, and predicted feed composition were determined not only by the rate of growth but also by body composition. Values for feed/gain included only actual amounts of feed eaten, but total production costs included normal feed wastage.

Simulated measures of feed and other costs for producing liveweight or carcass lean are shown in Table 2 for baseline levels of performance. Total production costs are considered quite typical. These results illustrate how various production inputs are associated with specific periods of the life cycle. Most feed inputs were associated with growing-finishing pigs while fixed costs were more closely associated with maintaining the breeding herd. Variable nonfeed costs were more evenly divided between pigs and sows.

The model was designed to be flexible. Genetic values for the primary traits may vary over wide ranges and may differ among generations to simulate heterosis effects. Inputs may be subtotaled into several categories, corresponding to different stages in the life cycle. Thus, several measures of efficiency can be calculated from each simulation. Other reports will describe how the model was used to answer specific questions about effects of alternative genetic changes on the efficiency of pork production systems.

[1]Tess is assistant professor of animal science, North Carolina State University (formerly MARC-supported Ph.D. student at the University of Nebraska–Lincoln); Bennett is a research scientist, Ruakura Agricultural Research Station, Hamilton, New Zealand (formerly MARC-supported post-doctoral associate, University of Nebraska–Lincoln); and Dickerson is a research geneticist, Genetics and Breeding Unit, MARC, stationed at Lincoln, Nebr.

Table 1.—Simulated performance for the baseline levels of performance traits

Performance traits	Parity 1	Parity 2	Parity 3
Mating liveweight----------lb---	257.0	288.0	313.0
Percent fat at mating----------	32.6	29.7	27.6
Daily gestation intake---------- Mcal ME---	5.84	6.65	7.25
Maternal gestation gain----------lb---	30.0	31.0	34.0
Percent fat at farrowing ----------	31.3	29.6	27.8
Percent of started gilts farrowing ----------	72.3	52.5	38.2
No. born alive----------	8.45	9.50	9.50
Ave. daily milk---------- Mcal ME---	7.84	9.21	9.21
No. weaned----------	7.19	8.08	8.08
Pig 21-day liveweight----------lb---	11.6	11.8	11.8
Pig 28-day liveweight----------lb---	15.4	15.7	15.7
Total creep intake/pig ---------- Mcal ME---	1.89	.74	.74
	Gilts	**Barrows**	
Age at 220 lb.----------days---	174	168	
Feed/gain:			
28 days to 49 lb ----------	2.14	2.15	
49 to 128 lb----------	2.85	2.86	
128 to 220 lb ----------	3.48	3.43	
Percent of CP in feed (all groups):			
28 days to 49 lb ----------	18.4		
49 to 128 lb----------	15.0		
128 to 220 lb ----------	13.5		

Table 2.—Simulated economic inputs for the baseline levels of performance

Inputs	Carcass lean	Liveweight	Total	Subtotal
	- -------- ($/100 lb) --------		---------- (pct) ----------	
Sow feed ----------	8.21	4.26	10.7	19.3
Pig feed----------	34.30	17.82	44.6	80.7
Total feed ----------	42.50	22.09	55.3	100.0
Sow variable----------	6.57	3.41	8.5	54.3
Pig variable ----------	5.53	2.87	7.2	45.7
Total variable----------	12.10	6.29	15.7	100.0
Sow fixed----------	14.14	7.36	18.4	71.7
Pig fixed ----------	5.57	2.90	7.3	28.3
Total fixed----------	19.71	10.26	25.7	100.0
Interest----------	2.53	1.31	3.3	-----
Total nonfeed[1] ----------	33.14	17.22	43.2	-----
Total----------	76.88	39.95	100.0	-----

[1]Includes interest on nonfeed costs.

Relative Importance of Performance Traits for Life-Cycle Costs of Pork Production under Alternative Production and Marketing Systems

Michael W. Tess, Gary L. Bennett, and Gordon E. Dickerson[1]

Introduction

Breeding goals must be clearly defined if the application of selection methods is to be most meaningful. Historically, breeding goals often have been based upon fads, with cyclical emphasis on size, conformation, color, and pedigree. To make real improvement in the efficiency of livestock production, breeders producing seedstock animals for the commercial industry need clear definition of the relevant biological objectives. The purpose of this study was to determine the relative importance of genetic changes in major performance traits for improvement in several measures of life-cycle unit production costs in purebred swine.

Procedure

Four definitions of unit costs were used. Megacalories of metabolizable feed energy (Mcal ME)/lb carcass lean marketed and Mcal ME/lb empty body weight marketed were measures of biological costs. Cost/100-lb carcass lean and cost/100-lb liveweight were measures of total economic costs. Inputs/unit of lean emphasize the body composition of pigs marketed and represent the future industry expectation that market pigs will be valued primarily on their lean meat content. Current marketing practice in the U.S. pays little premium for leanness; hence, input/unit of liveweight output represents short-terrn breeding goals.

Seven traits were considered: increased number born alive/litter (NBA), conception rate (CR), milk production (MK), preweaning viability (VIAB), and growth rate (GR), plus decreased age at puberty (–PUB), and lower percentage of carcass fat at 220 lb (–%F).

A deterministic, bio-economic computer model of purebreeding pork production was used to simulate life-cycle performance and cost/unit of output. Each genetic trait was evaluated independently by simulating the effects of changes in the genetic means for each trait with no correlated changes in the genetic means of the other traits. The base management system represented a continuous farrowing system with litters weaned at 28 days. Sows were allowed a maximum of two estrous cycles after weaning to rebreed and were kept in the breeding herd for a maximum of three parities. Market pigs were sold either at 220-lb or at the mean weight for a fixed age. Effects of other changes in the management and marketing system upon the relative importance of the genetic traits also were studied and will be summarized in the results.

Results

Changes in production costs from independent 20 percent genetic changes in the means of each trait are presented in Table 1 (CR and VIAB were only changed 15 pct). Expressed as percentages of the base levels, —PUB and CR reduced costs similarly but more for nonfeed than for feed items. Both —PUB and CR reduce inputs associated with developing replacement gilts. CR also increases average litter size by decreasing the proportion of gilt litters in the system.

Increases in NBA and VIAB similarly spread the largely nonfeed inputs associated with sow development, maintenance, and farrowing over more output. Hence, NBA and VIAB had larger effects on total costs than on feed inputs/lb of output.

Changes in MK had little effect on costs because simulated base levels for MK were adequate to meet litter needs. In populations where MK is less adequate, simulated litter growth and survival would be reduced and costs increased.

Responses to changes in GR and –%F were very sensitive to the definition used for efficiency. Increased growth-to-market weight of 220-lb (GR_W) made pigs more efficient users of feed and leaner at 220-lb market weight. Reducing %F had larger effects on lean content and smaller effects on feed intake. Both GR and –%F had larger effects on feed inputs than on total costs, primarily because feed prices were higher for the fast-growing or leaner pigs, or both, because of their increased protein intake requirements. Reducing %F had detrimental effects upon cost/lb

Table 1.—Simulated percentage changes in biological (Mcal) and economic ($) cost/lb of lean or body weight output from a 20 percent mean genetic improvement in each trait[1]

	Traits[2]							
Cost/output	–PUB	CR[3]	NBA	MK	VIAB[3]	–%F	GR_W[4]	GR_A[5]
Mcal ME/lb carcass lean	–1.9	–1.2	–2.3	–0.1	–2.1	–11.4	–4.5	–1.7
Mcal ME/lb empty body weight	–1.8	–1.1	–2.1	.1	–2.0	–2.3	–2.4	–1.7
$/100 lb carcass lean	–2.4	–2.0	–5.3	– .1	–4.8	–7.8	–3.3	–6.7
$/100 lb liveweight	–2.3	–1.9	–5.2	.1	–4.7	1.6	–1.1	–6.7

[1]All values are percentages of costs for baseline levels of performance traits.
[2]See text for definition of traits.
[3]CR and VIAB changed only 15 percent.
[4]GR_W = increased growth rate when pigs are marketed at 220 lb.
[5]GR_A = increased growth rate when barrows and gilts are marketed at mean 168- and 174-day weights, respectively.

Table 2.—Percentage changes in biological (Mcal) or economic ($) cost/lb of carcass lean or body weight output from 1 genetic standard deviation of improvement in the mean for each trait[1]

	Traits[2]					
Cost/output	–PUB	NBA[3]	VIAB	–%F	GR_W[4]	GR_A[5]
Mcal ME/lb carcass lean	–0.6	–0.6	–0.7	–3.8	–1.4	–0.5
Mcal ME/lb empty body weight	– .6	– .6	– .6	– .7	– .7	– .4
$/100 lb carcass lean	– .8	–1.5	–1.6	–2.7	– .9	–2.1
$/100 lb liveweight	– .7	–1.5	–1.5	.4	– .2	–2.1

[1]All values are percentages of costs for baseline levels of performance traits.
[2]See text for definition of traits.
[3]Response divided by 2 because selection is based on dam's record.
[4]GR_W = increased growth rate when pigs are marketed at 220 lb.
[5]GR_A = increased growth rate when barrows and gilts are marketed at mean 168- and 174-day weights, respectively.

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liveweight because no premium was paid for lean, and total sow and pig feed costs were higher/100-lb liveweight marketed.

Changes in unit production costs expressed/genetic standard deviation of improvement in each trait indicate the relative importance of traits for constructing selection indexes (Table 2). Changes in MK were not included in Table 2 because increasing MK above base levels had no effect on costs. Increased CR was omitted because it is not well suited for within-herd selection. Growth traits (GR_W and –%F) were more important than reproduction for reducing feed inputs/lb of carcass lean, especially for –%F, but not for feed/lb of liveweight output. The importance of NBA and VIAB increased when all production expenses were included. Reducing %F was still most important for total cost/unit lean but was slightly detrimental to cost/unit liveweight. When no premium was paid for lean content, NBA and VIAB were the most important traits for reducing cost/unit output.

Effects of management and marketing changes on the trait evaluations were also studied. Increasing sale weight or reducing farrowing intervals increased the importance of growth traits relative to reproduction traits but not enough to change the rankings of the traits. Doubling feed prices relative to nonfeed expenses reduced the importance of reproductive traits for total costs but also magnified the detrimental effects of –%F on cost/unit of liveweight.

The relative importance of GR is greatly increased by marketing faster growing pigs at heavier weights. Faster growing pigs are heavier but similar in fat percentage to slower growing pigs of the same age. The much greater reductions in total costs for increased growth to a mean weight at 168- and 174-day weights for barrows and gilts, respectively (GR_A) than for GR_W in Tables 1 and 2 illustrate that the real potential of GR for improving economic efficiency occurs because GR provides a means of increasing sale weight and thus spreading all costs associated with sows over more output. When pigs were marketed by age, GR_A was the most important trait for cost/unit liveweight and was only exceeded by –%F for cost/unit of lean. Marketing policy did not affect the relative importance of traits other than GR.

The following conclusions seem warranted from these results: (1) the relative economic importance of faster growth rate and reduced fatness in selection programs is extremely sensitive to marketing policy and price differentials for leanness; (2) reducing fatness greatly reduces both feed and total costs/unit of lean output, but not costs/unit of liveweight; (3) marketing at mean weight for a constant age greatly increases the relative value of faster growth rate; and (4) maternal and litter traits have more important effects on total costs than on feed inputs and become relatively more important when little premium is paid for higher yield of lean meat from the carcass.

Expected Crossbreeding Effects on Performance Traits and Costs of Pork Production

Gary L. Bennett, Michael W. Tess, Gordon E. Dickerson, and Rodger K. Johnson[1]

Introduction

Important beneficial crossbreeding (heterosis) effects have been documented in many swine experiments for such traits as the viability and growth of pigs and the fertility, prolificacy, and mothering ability of sows. Crossbreeding effects on efficiency of pork production are often expressed as increased litter weight marketed/sow. However, because about 60 percent of all costs are for postweaning growth of pigs, the effects of crossbreeding on system efficiency are measured more realistically by reduction in total costs of production.

This report summarizes results from simulating effects of known crossbreeding responses in basic biological traits on total costs/unit of lean or liveweight output with the aid of the pork production systems model described earlier.

Procedure

Pig heterosis was estimated by comparing crossbred litters from purebred sows with purebred litters, and sow heterosis was estimated by comparing crossbred vs purebred sows all producing crossbred litters when all breeds were assumed equal in purebred performance. Degree of heterosis simulated for underlying biological components of performance was based on results from numerous published crossbreeding experiments.

Important assumptions were that (1) feed for maintenance and growth and lactation are dependent on lean mass, amount of protein and fat deposited or lost, and level of milk production; and (2) sow litter size and milk production and pig genotype together determine pig survival, growth, and composition until creep feeding begins. Heterosis effects were simulated by changing birth weight, growth rate of protein and of fat, preweaning viability, age at puberty, conception rate, litter size, and milk output. Relative importance of heterosis in each component was estimated from the effect of omitting heterosis for each component singly from the total crossbreeding effect.

The four measures of production efficiency used were feed energy (Mcal) or total cost ($) per unit of carcass lean or liveweight output, evaluated for marketing at 220-lb liveweight or at average 185-day liveweight. Other features were maximum of three litters/sow, weaning at 7 weeks, and creep feeding from 3 to 7 weeks. Replacements were purchased at cost of 1,200 Mcal or $100/220-lb gilt, regardless of breeding. Typical midwestern housing and other production costs were used, including $2.50/bushel for shelled corn.

Results

Assumed pig heterosis (i.e., in crossbred vs purebred litters from purebred sows, Table 1) was primarily in pig viability and growth rate with small increases in birth weight and fatness. Sow heterosis (i.e., crossbred vs purebred sow with crossbred litters) was greatest for litter size and milk production, also important for age at puberty, fertility, and preweaning pig viability but slight for backfat and zero for postweaning growth rate.

Total costs/lb of lean were reduced substantially (–4 pct) by either pig or sow heterosis and more than –8 percent by both (i.e., in crossbred litters from crossbred sows) for marketing at 220-lb liveweight. If pigs were marketed at mean 185-day weight, the effect would be larger for pig heterosis (–6.3 pct) because of the increased weight marketed for the same sow cost but slightly less for sow heterosis (–4.1 pct) because sow costs became a smaller proportion of total costs.

Total costs/lb of liveweight were reduced more than cost/lb of lean by pig heterosis because crossbred pigs were a little fatter, especially when marketed at mean 185-day weight (–4.3 vs –3.8 and –8.2 vs –6.3 pct). Effects of sow heterosis were the same for lean or liveweight.

Effects of sow heterosis on only the biological efficiency, or feed energy/unit of lean or liveweight output, were much smaller than on total costs (–1.3 to –1.6 vs –4.0 to –4.5 pct) because of the large proportion of sow costs for nonfeed items. Effects of pig heterosis were 60 to 70 percent as large for feed energy alone as for total costs of lean or liveweight when pigs were marketed at 220 lb because of the high proportion of total pig inputs for feed alone. When pigs were marketed at mean 185-day weight, the heterosis increase in fatness was accentuated enough to cancel the favorable effect of growth heterosis reduction in feed energy/lb of lean marketed at a fixed 220-lb liveweight (0.1 vs –1.6 pct), but feed energy/lb liveweight was relatively unaffected (–1.3 vs –1.6 pct).

Pig heterosis reduces total costs primarily through better pig viability and through faster growth rate only if the faster

Table 1.—Pig and sow heterosis for individual traits and effects on feed (Mcal) and total costs ($) per lb of lean or liveweight (LWT) output marketed at 220 lb liveweight (or at mean 185-day weight) as a percentage of purebred mean

Item	Purebred mean	Heterosis (pct)	Mcal/lb of Lean	Mcal/lb of LWT	$/lb of Lean	$/lb of LWT
Purebred mean			10.36	5.69	0.87	0.455
Pig heterosis:						
Birth weight ----------lb---	2.95	2.1	0	0	0	0
Viability ----------percent---	71.0	7.2	–2.0	–1.8	–4.2	–4.0
Growth rate ----------lb/d---	1.43	9.4	–1.6 (0.1)	–1.6 (–1.3)	–.4 (–3.0)	–.4 (–4.3)
Backfat----------in---	1.1	1.1	.8	.2	.6	0
Total			–2.6 (–0.8)	–3.1 (–2.8)	–3.8 (–6.3)	–4.3 (–8.2)
Sow heterosis:						
Puberty age----------days---	208.0	–3.8	–.4	–.3	–.4	–.4
Fertility----------percent---	72.0	4.2	–.3	–.3	–.5	–.5
Litter size born ----------no---	8.96	10.5	–.9	–.9	–2.2	–2.1
Max. milk ----------Mcal/d---	8.2	10+	–.7	–.6	–2.1	–2.0
Litter viability[1] --------percent---	71.0	2.6	.3	.2	.4	.3
Growth rate[1] ----------lb/d---	1.43	0	.6 (0.7)	.4 (0.5)	0 (0.4)	– .3 (0.2)
Backfat[1] ----------in---	1.1	.4	0	0	–.1	–.1
Total			–1.6 (–1.4)	–1.4 (–1.3)	–4.5 (–4.1)	–4.5 (–4.0)

[1]Above levels from pig heterosis.

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growing crossbreds are marketed at their heavier weights for the same age (Table 1). The slightly increased fatness of crossbreds actually would increase cost/lb of lean. Sow heterosis reduces total costs largely by increasing litter size and sow milk production and about one-fourth as much by earlier puberty and increased fertility. The net effect of 9-percent increased growth rate of crossbred gilts (on sow replacement and maintenance costs and salvage income) was slightly adverse for feed energy/unit of lean and liveweight output to either marketing end point (0.4 to 0.7 pct), but total costs were increased only for 185-day marketing because the large sow nonfeed costs were not increased, and sow salvage output was increased.

A small increase was shown in both feed and total costs for maternal heterosis in litter viability (0.2 to 0.4 pct) apparently because the cost for extra milk from crossbred sows more than offset effects of the small increase (0.19) in number of crossbred pigs weaned.

Heterosis reduced other costs much more than feed costs for either lean or liveweight (Table 2) because the large sow nonfeed costs were spread over more output. Thus, an increase in feed prices relative to nonfeed prices would reduce the average heterosis advantage in total costs/unit of output. The greater heterosis for other than feed costs was more pronounced for sow than for pig performance when marketing was at 220-lb liveweight; however, when marketing was at mean 185-day weight, the reduction in other costs of lean or liveweight from pig heterosis was much greater because these costs were spread over more product marketed. There was less reduction in feed costs/lb of lean because of the still greater fat content at 185 days. Sow heterosis effects were reduced a little because sow costs became a smaller fraction of total costs.

In general, the reductions in total costs from sow plus pig heterosis were only about one-third as large, percentagewise, as the corresponding increases in total output marketed/litter because of the extra costs associated with the greater output/sow from crossbreeding systems.

Table 2.—Percentage effects of pig and of sow heterosis on feed and on other costs/unit of lean or of liveweight output

		$/lb lean			$/lb LWT		
Marketing	Heterosis	Feed	Other	Total	Feed	Other	Total
100 kg LWT--	Pigs	−2.4	−5.1	−3.8	−3.0	−5.7	−4.3
	Sows	−1.5	−7.9	−4.5	−1.4	−7.7	−4.5
	Total	−3.9	−13.0	−8.3	−4.4	−13.4	−8.8
185-day mean weight ------	Pigs	−1.2	−11.8	−6.3	−3.2	−13.5	−8.2
	Sows	−1.3	−7.1	−4.1	−1.2	−7.0	−4.0
	Total	−2.5	−18.9	−10.4	−4.4	−20.5	−12.2

Effects of Product Definition, Management, and Breeding-System Role on Selection Criteria in Swine

Charles Smith, Gordon E. Dickerson, Michael W. Tess, and Gary L. Bennett[1]

Introduction

The relative biological and economic importance of genetic changes in major performance traits of pigs has been summarized in other reports for cost of lean vs liveweight output under different management and marketing systems and for different breed roles in commercial pork production systems. Differences among such sets of relative economic weights of traits certainly will cause some differences in selection emphasis on traits to maximize the expected rate of improvement. We need to know, however, how much of the maximum potential improvement under a particular system or breed role is likely to be lost when selection actually is based upon the economic weightings of some other system or breed role. In other words, how many different sets of economic weights and corresponding selection index weightings are really justified to achieve near maximum potential rates of swine improvement?

This report examines the relative loss in expected rate of response from selection when the economic weightings of traits used were based on systems or breed roles other than the one for which improvement was desired.

Procedure

The basic procedure was to compare response expected from selection based on the most appropriate relative economic ($/1b) importance of performance traits (ΔH) with the correlated response ($\Delta H'$) expected when selection was based on relative importance of traits for some other marketing or management system or breed role. Then $1-{}^{\Delta H'}/_{\Delta H}$ = fractional loss of selection efficiency.

Relative importance of traits for differing production, marketing, and breeding systems was taken from previous simulation studies. Relative importance is expressed as expected percentage change in cost/lb of lean or liveweight output for one phenotypic standard deviation of improvement in a given trait: (1) in Table 1 for the base purebreeding and several alternative management systems, and (2) in Table 2 for different possible breed roles in commercial pork pro-

Table 1.—Effect on biological (Kcal/lb) and economic ($/lb) costs/phenotypic standard deviation of desired change in traits for carcass lean or liveweight output and 5 management systems as percentage of base mean

		Management system				
		$/100 lb				
Criterion trait[1]	Kcal/lb base	Base	+ Farrow interval	+ Market weight	+ Feed price	Marketing by age
Carcass lean—mean:	9.71	76.72				
Age at puberty (−PUB)	−1.0	−1.2	−1.3	−1.1	−1.8	−1.2
Fertility (CR)	−4.2	−6.4	−6.6	−5.7	−9.1	−6.4
Litter size born (NBA)	−3.2	−7.7	−8.4	−7.0	−9.5	−7.8
Pig viability (VIAB)	−3.0	−7.0	−7.8	−6.3	−8.6	−7.0
Growth rate (GR)	−2.5	−1.7	−1.7	−2.0	−2.6	−3.8
Fatness (−FAT)	−6.1	−4.4	−4.5	−4.2	−6.3	−4.2
Live weight—mean:	5.30	39.87				
−PUB	−.9	−1.2	−1.2	−1.1	−1.7	−1.2
CR	3.0	6.0	−6.1	−5.5	−8.8	−6.1
NBA	−3.0	−7.5	−8.4	−6.8	−9.2	−7.6
VIAB	2.8	−6.7	−7.7	−6.1	−8.4	−6.8
GR	−1.3	−.4	−.5	−.7	−.6	−3.7
−FAT	−1.2	.6	.6	1.0	1.6	.8

[1]Direction of change desired is indicated by sign of trait (e.g., −PUB).

Table 2.—Effect on costs/phenotypic standard deviation of desired change in performance traits for 10 breeding roles and base management system as a percentage of base mean[1]

			Rotation X						Paternal	
Criterion trait[2]	Purebreed	Backcross S&MGD	2-breed	3-breed	Backcross MGS	Three-breed MGS	Two-breed dam	Three-breed MGD	2S	3S
$/100 lb lean:										
−PUB	−1.3	−1.0	−1.1	−1.0	−1.6	−1.5	−2.8	−1.5	0	0
CR	9.6	−8.6	−8.1	−7.7	−12.5	−12.9	−20.9	−25.9	−.2	−.2
NBA	−7.9	6.1	−6.5	−6.2	−10.4	−9.4	−13.6	−16.8	−.2	−.2
VIAB	−7.8	−6.7	−6.4	−6.2	−7.7	−7.4	−9.8	−10.0	−5.1	−4.7
GR	−.1	.7	−.4	−.4	−.1	−.3	−1.1	−1.1	−.2	−.9
−FAT	−4.4	−3.7	−3.9	−3.5	−3.9	−3.9	−4.9	−4.8	−2.9	−2.9
$/100 lb LWT:										
−PUB	−1.3	−.9	−1.1	−.9	−1.5	−1.5	−2.5	−2.7	0	0
CR	−8.8	−8.0	−7.6	−7.2	−11.6	−12.4	−20.0	−24.8	0	0
NBA	−7.8	−6.0	6.4	−6.0	−10.3	−9.2	−13.2	−16.4	−.2	−.2
VIAB	−7.7	−6.6	−6.3	−6.0	−7.5	−7.2	−9.6	−9.8	−4.9	−4.5
GR	−.2	−.8	.2	−.4	−.2	−.4	−1.4	−1.1	0	−.8
−FAT	.7	.6	.5	.5	.7	.6	1.1	.8	.3	.2

[1]Effects for each breed role have been divided by its fractional contribution to pedigree of crossbred market pigs to permit easier comparison of breed roles.
[2]See Table 1 for definition

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duction systems. Notice that improvement in reproductive traits—fertility (CR), litter size born (NBA), and pig viability (VIAB)—reduced total costs ($/100 lb) of either lean or liveweight output much more than they reduced feed energy (Kcal/lb) inputs. However, improvements in growth-carcass traits, growth rate (GR) and fatness (–FAT) reduced $/100 lb less than Kcal/lb inputs, and –FAT actually increased $/100 lb liveweight slightly.

Longer intervals between farrowings only increased importance of NBA and VIAB slightly. Marketing at heavier weights reduced importance of reproductive traits a little and further increased cost/lb liveweight from –FAT. Higher prices for feed relative to other inputs increased the absolute $/lb importance of genetic improvement in all traits, including the unfavorable effect of –FAT on cost/lb liveweight. Marketing faster growing pigs at the heavier mean weight of a fixed age sharply increased the importance of GR, especially for cost/lb of liveweight output.

Relative importance of traits differed little among purebreeding, primary backcross, and rotation crossbreeding roles, but importance of CR, NBA, VIAB, and age at puberty (–PUB) progressively was greater for breeds used as backcross and three-breed cross maternal grandsire, two-breed cross dam, and three-breed cross maternal granddam, especially for CR, NBA, and –PUB. Value of faster GR also increased for the two- and three-breed maternal roles. In paternal two- and three-breed crossing roles, VIAB was important for cost/lb of both lean and liveweight, but –FAT was important only for cost/lb of lean. GR was of lesser importance in breeds siring three-breed crosses in the base system for marketing at 220 lb but would be much more important under marketing at mean weight for a fixed age (see Table 1).

Heritabilities and correlations among the traits considered (Table 3) also influence optimum emphasis in selection and both the direct and correlated responses expected. Values shown in Table 3 were averages from several reported studies. High and low values of heritability for reproductive traits were tried to evaluate their effects on expected results.

Results

The products of heritability and $/lb importance shown in Table 4 indicate the relative selection index weighting that would be optimum for the base production system if the traits were uncorrelated because the measure of $/lb importance included trait differences in variability (i.e., per standard deviation). Note that the differences between index weightings for low and high heritability of CR, NBA, and VIAB were the same for cost/lb of lean or liveweight. Weightings for cost/lb of lean, however, would be strongly positive for GR and negative for FAT. But for costs/lb of liveweight, index weightings would decline sharply for GR and even change direction for FAT.

Loss in selection response expected from using a selection index based upon different sets of heritabilities or definitions of system efficiency is presented in Table 5 as a percentage of response expected from correct index weightings. Little loss was expected from the difference between the high and low heritabilities for CR, NBA, and when selecting for lower cost/lb of lean (Table 3), but the expected loss in response was larger when selecting for cost/lb of liveweight because reproductive traits have relatively greater importance when there is no premium for leanness (Tables 1 and 4).

Selection for Kcal/lb or $/lb cost of lean output is nearly identical because selection for leanness dominates the index even when heritability of CR, NBA, and VIAB is at the higher level. Selection for lower Kcal/lb of lean or of liveweight output also is very similar. Selection for

Table 3.—Estimated heritabilities (diagonal), phenotypic (above diagonal), and genetic (below diagonal) correlations among performance traits (X 100)[1]

Trait	PUB	CR	NBA	VIAB	GR	FAT
PUB ---------	30					
CR ----------		1 or 5				
NBA ---------			5 or 15		–6	–5
VIAB[2] -------				5 or 10		
GR ----------	10				35	–7
FAT ---------					–20	40

[1]Phenotypic correlations are among dam's records for reproductive traits and individual growth-carcass traits. All genetic correlations are among individuals. All blanks were assumed to be zero.
[2]Litter mean viability adjusted to a standard number born alive.

Table 4.—Product of heritability (h^2, table 3) and base percentage economic importance (table 1) for cost of carcass lean or of liveweight and 2 levels of heritability for reproductive traits (h^2)

	Criteria:	$/100 lb carcass lean		$/100 lb liveweight	
Trait[1]	Levels h^2:	High h^2	Low h^2	High h^2	Low h^2
–PUB[2] ----------		–0.18	–0.18	–0.17	–0.17
CR[2] ----------		–.16	–.03	–.15	–.03
NBA[2] ----------		–.58	–.20	–.57	–.19
VIAB[2] ----------		–.35	–.17	–.34	–.17
GR ----------		–.60	–.60	–.15	–.15
–FAT ----------		–1.74	–1.74	.25	.25

[1]See table 1 for definitions.
[2]Effective heritability is one-half that in Table 3 for selection of individuals on dam's record.

Table 5.—Percentage loss in expected correlated response for index 1 when selection based on index 2

Selection base					Percent loss in response	
Index 1	Index 2	Criterion[1]	Management system	Heritability reproduction[2]	2 on 1	1 on 2
High h^2 (reproductive traits)	Low h^2	$/lb lean	Base	----	–2	–2
		$/lb LWT			–10	–10
Kcal/lb lean	$/lb lean	----	Base	High	–3	–3
				Low	–1	–1
Kcal/lb LWT	$/lb LWT[1]	----	Base	High	–78	–78
				Low	–100	–109
Kcal/lb lean	Kcal/lb LWT	----	Base	High	–8	–8
				Low	–6	–6
$/lb lean	$/lb LWT	----	Base	High	–91	–91
				Low	–130	–130

[1]LWT = liveweight.
[2]See Table 3.

Table 6.—Percentage loss in expected correlated response (relative to full base index) from omitting traits or from using U.S. NSIF or U.K. MLC Indexes

Measure of efficiency:	$/100 lb lean		$/100 lb liveweight	
Heritability, Item reproduction:	High	Low	High	Low
Traits omitted:				
PUB	−1	−1	−3	−10
CR	−1	−1	−2	−1
NBA	−3	−1	−37	−14
VIAB	−1	−1	−11	−9
GR	−8	−8	−1	−4
FAT	−46	−53	−6	−21
All reproductive	−5	−1	−67	−39
Industry indexes[1]				
U.S. NSIF index	−19	−17	−64	−98
U.K. MLC index	−12	−9	−111	−120

[1]NSIF economic weightings were −9.8 for NBA, −2.8 for GR, and −1.2 for —FAT and MLC; weightings were −2.2 for GR and −1.6 for —FAT where weighting for GR and —FAT included genetic correlations (0.7 and 0.3) times weighting for feed conversion.

Table 7.—Percentage loss in expected correlated responses between pairs of selection indexes based on economic weights for 5 management systems[1]

System	1	2	3	4	5
1. Base	All loss less than 5 percent for				
2. Longer farrowing interval	$/100 lb lean or liveweight,				
3. Heavier sale weight	except for $/100 lb liveweight				
4. Higher feed price	between system 5 and other systems.				
5. Marketing at mean ---- high[2]	−39	−37	−35	−49	
weight for fixed age ----- low	−54	−50	−48	−72	

[1]See Table 1 for economic weights.
[2]Heritabilities for reproductive traits, see Table 3

Table 8.—Percentage loss in expected correlated response between pairs of selection indexes based on economic weights for 10 breed roles and base management system[1]

Breed rule		1	2	3	4	5	6	7	8	9^2	9^3	9^4	9^5
Purebreeding	1	All losses less than −5 percent except among											
Backcross, S + MGD	2	−17	roles 1 to 8 for $/lb live-										
Rotation, two-breeds	3	−1	−15	weight and low heritability[5]									
Rotation, three-breeds	4	−3	−5	−3	as shown								
Backcross, MGS	5	−1	−18	−1	−4	below diagonal.							
Specific crosses:													
Three-breed, MGS	6	−3	−10	−1	−2	−2							
Two-breed, dam	7	−14	−2	−11	−4	−13	−6						
Three-breed, MGD	8	−13	−5	−10	−5	−11	−4	−1					
Two-breed, sire	9^2	−6	−5	−5	−5	−12	−10	−13	−18				
	9^3	−2	−1	−1	−1	−3	−2	−3	−4				
	9^4	−40	−43	−41	−41	−49	−51	−56	−62				
	9^5	−25	−41	−39	−30	−32	−38	−50	−55				
Three-breed, sire	10^2	−8	−5	−6	−6	−14	−12	−12	−18	−2			
	10^3	−4	−3	−2	−2	−5	−4	−3	−4		−1		
	10^4	−60	−37	−39	−50	−66	−60	−50	−58			−40	
	10^5	−73	−26	−69	−50	−76	−61	−36	−45				−70

[1]See Table 2 for economic weights.
[2 3]$/100 lb lean for high and low heritabilities for reproductive traits, respectively.
[4 5]$/100 lb liveweight for high and low heritabilities, respectively.

lower Kcal/lb of liveweight, however, produces little of the response expected from selecting for lower $/lb of liveweight, or the reverse, because of the difference in the importance of GR and –FAT (Table 1). Also, there is great antagonism between selection based on cost/lb of lean and that based on cost/lb of liveweight because of the small $/lb weightings for GR and FAT when there is no premium for leanness (Table 1).

Loss from omitting traits (Table 6) in selecting for cost/lb of lean was greatest for omitting –FAT, moderate for GR, and very little for omitting all reproductive traits. For cost/lb of liveweight, omitting all reproductive traits was very serious; omitting –FAT was less serious for high than for low heritability (Table 3) of CR, NBA, and VIAB. Compared with complete index selection for cost/lb of lean, loss from using the National Swine Improvement Federation (NSIF) index for only NBA, GR, and –FAT was –19 or –17 percent; the British Meat and Livestock Commission (MLC) index, with relatively more emphasis on –FAT but none on NBA, was a bit closer to the complete index. Predicted loss in response compared with complete index selection for lower cost/lb of liveweight was much greater for both the NSIF and MLC indexes because of the difference in size and even direction of economic importance for GR, –FAT, and reproductive traits (Tables 1 and 4).

Management and marketing systems had relatively little effect on the responses from index weightings of performance traits except for differences in cost/lb of liveweight between marketing at weight for a fixed age and the other four systems as shown in Table 7. The discrepancy between correlated and direct index responses was larger for low than for high assumed heritabilities because the lower heritabilities of CR, NBA, and VIAB shifts emphasis to GR and FAT that are affected most by marketing at a fixed age vs weight.

Breed role in production systems had major effects on expected correlated vs direct responses from selection (Table 8) only for cost/lb of liveweight between paternal breed roles in two- or three-breed crossing vs all other breed roles in production systems.

Most important different index weightings are between those intended to reduce:

—$/100 of lean vs liveweight

—Kcal/lb vs total cost/lb of liveweight,

—$/100-lb liveweight, for marketing by age vs a fixed weight, or

—$/100-lb liveweight, for terminal sire vs other breed roles.

For cost/lb lean output, reduced fat (–FAT) is the most important single trait; for cost/lb liveweight, reproductive traits are most important. Relatively little conflict exists between selection to reduce biological (feed energy) cost/lb of lean vs liveweight output or between selection for biological vs total economic cost/lb of carcass lean output.

Selection for reduced cost/lb of carcass lean, with marketing at mean weight for a fixed age, offers greatest opportunity to reduce production costs of lean pork output and least conflict between optimal selection criteria for different management systems and breed roles.

Evaluation of Purebred Performance of Eight Swine Breeds

Kreg A. Leymaster, Gordon E. Dickerson, and Larry D. Young[1]

Introduction

Swine production efficiency can be improved significantly by applying well established genetic principles. The primary genetic tools available to the swine industry are selection programs to improve existing breeds and crossbreeding systems to utilize heterosis (hybrid vigor) and genetic differences among breeds. Each of these concepts is being investigated in long-term swine-breeding projects at MARC. Although the research projects have not been completed, sufficient data have been collected on purebred pigs to justify a preliminary report. The objective of this report is, therefore, to summarize reproduction, growth, carcass, and puberty data obtained on samples of purebred pigs representing eight breeds. The information on breed characteristics should be interpreted cautiously, however, because the pigs evaluated represent only a sample from each breed and because purebred performance may not indicate relative usefulness of the breeds in crossbreeding programs.

Procedure

Herds of eight swine breeds, (Chester White, Duroc, Hampshire, Swedish Landrace, Large White, Pietrain, Spot, and Yorkshire) were established at MARC by 1978. Approximately eight boars were used/breed each year. Chester White, Swedish Landrace, Large White, and Yorkshire gilts farrowed during February and March (spring-farrowing group) of each year. Duroc, Hampshire, Pietrain, and Spot gilts farrowed annually during September and October (fall-farrowing group). Pigs were raised by their own dams and had access to creep feed at 14 days of age. Pigs were weaned at 28 days of age into a nursery, weighed at 56 days of age, and moved to growing-finishing facilities 1 week later. Two boars and up to 2 barrows/litter were penned together, while gilts were penned in groups of 18 to 22/pen. Growth and feed consumption data were recorded at 28-day intervals from 70 to 154 days of age. Carcass data were obtained on barrows at slaughter weight. Gilts were moved to another building at 154 days of age and checked daily for estrus through the first breeding season to about 9 months of age.

Results

Data were analyzed for pigs born in 1979, 1980, and 1981. Data for the spring- and fall-farrowing groups were analyzed separately. Thus, comparison of breeds born in the spring-farrowing group to breeds born in the fall-farrowing group include season effects as well as any real breed differences.

Breed means for litter traits measured to weaning are presented in Table 1. Each year was weighted equally in calculating the breed means. In the spring-farrowing group, Swedish Landrace exceeded Large White and Yorkshire, and Chester White was lowest for various measures of prolificacy. The number of stillborn pigs was similar for the four white breeds, but better preweaning survival was associated with larger litter size at birth among these breeds. The net effect of Swedish Landrace advantages for number born alive, litter birth weight, survival percentage, and number weaned resulted in Swedish Landrace litters being 21, 23, and 59 percent heavier at weaning than litters produced by Large White, Yorkshire, and Chester White gilts, respectively.

Of the four breeds in the fall-farrowing group, gilts of the Duroc breed consistently ranked the highest for the various traits measured to weaning. Rankings of the Hampshire, Pietrain, and Spot breeds varied depending on the trait under consideration. Duroc gilts weaned litters 5-, 15-, and 22-percent heavier than litters weaned by Hampshire, Pietrain, and Spot gilts, respectively.

Breed means for growth, carcass, and puberty traits of individual pigs are presented in Table 2. The effects of years, breeds, sexes, and changes in sex effects between years and breeds were evaluated. Among breeds farrowed in the spring, Swedish Landrace pigs were heaviest at birth despite being born into the largest litters. Average pig-weaning weight varied slightly among breeds, but Yorkshire pigs were lightest at 70 days of age. Average daily gain between 70 and 154 days of age was greater for Large White and Swedish Landrace than for Chester White and Yorkshire pigs. Large White pigs were the heaviest, therefore, at 154 days of age, followed by Swedish Landrace, Chester White, and Yorkshire pigs.

Among breeds farrowed in the fall, Spot pigs were consistently heavier at each age than pigs produced by the other breeds. Average daily gain was greatest for Spot pigs and lowest for Pietrain pigs. As a consequence of these growth patterns, differences of up to 20 percent existed among paternal breeds for 154-day weight.

Carcass data were adjusted to a 165 lb carcass weight basis using separate regressions for each breed. Among the

[1]Leymaster and Young are research geneticists at MARC, and Dickerson is a research geneticist stationed at the University of Nebraska–Lincoln.

Table 1.—Breed means for litter traits measured to weaning, 1979 to 1981

	Spring-farrowed breeds[1]				Fall-farrowed breeds[2]			
Trait	C	L	W	Y	D	H	P	S
No. litters	47	68	69	66	84	83	79	90
Total no. born[3]	8.2	9.6	8.5	8.6	8.8	8.2	7.5	8.0
No. born alive	7.5	9.0	7.9	7.9	7.9	7.5	6.8	7.0
No. stillborn	.8	.6	.7	.7	.9	.7	.7	1.0
Litter birth weight, lb[4]	21.8	28.9	21.4	20.3	24.5	22.0	20.7	23.4
Survival, percent[5]	64.5	87.7	83.8	79.9	82.4	79.3	82.0	68.4
No. weaned	4.9	7.8	6.5	6.6	6.4	5.9	5.6	4.8
Litter weaning weight, lb	68.0	108.0	89.0	88.0	82.0	78.0	71.0	67.0

[1]Chester White (C), Landrace (L), Large White (W), and Yorkshire (Y) farrowed in February and March
[2]Duroc (D), Hampshire (H), Pietrain (P), and Spot (S) farrowed in September and October
[3]Total of pigs born alive and stillborn.
[4]Includes birth weights of stillborn pigs as well as birth weights of pigs born alive.
[5]Percentage of pigs born alive that survived to weaning at 28 days of age.

Table 2.—Breed means for growth, carcass, and puberty traits of individual pigs, 1979 to 1981

Trait	Spring-farrowed breeds[1]				Fall-farrowed breeds[2]			
	C	L	W	Y	D	H	P	S
Growth:[3]								
Birth weight ----------lb---	2.65	3.00	2.49	2.36	2.80	2.67	2.78	2.93
Weaning weight ----------lb---	13.8	13.9	13.8	13.5	12.8	13.4	12.6	14.1
70-day weight ----------lb---	42.5	43.0	43.7	39.5	39.5	35.7	36.6	48.3
154-day weight ----------lb---	172.0	180.0	184.0	169.0	172.0	164.0	154.0	190.0
Avg. daily gain ----------lb/day[4]---	1.54	1.63	1.68	1.54	1.59	1.52	1.41	1.70
Carcass:[5]								
Length ----------in---	31.0	32.7	32.0	31.5	30.4	30.9	28.7	30.9
10th rib backfat ----------in---	1.08	1.02	.98	1.06	1.17	1.06	1.34	1.04
Loin eye area---------- in^2---	4.73	4.59	4.87	4.98	4.53	5.18	5.41	4.84
Puberty:								
Percentage cycling[6] ----------	83.7	98.1	91.2	85.5	82.9	80.5	90.9	88.5
Age at puberty --------- days[7]---	209.0	184.0	208.0	222.0	229.0	213.0	199.0	198.0

[1]Chester White (C), Landrace (L), Large White (W), and Yorkshire (Y) farrowed in February and March.
[2]Duroc (D), Hampshire (H), Pietrain (P), and Spot (S) farrowed in September and October.
[3]Average of boar, barrow, and gilt growth data.
[4]Average daily gain from 70 to 154 days of age.
[5]Data on barrows adjusted to 165 lb carcass weight.
[6]Percentage of gilts exhibiting estrus.
[7]Based on gilts detected in estrus.

spring-farrowed breeds, Swedish Landrace and Large White barrows had longer carcasses and less backfat at the 10th rib than Chester White and Yorkshire barrows. Yorkshires produced the largest loin eyes, followed by Large White, Chester White, and Swedish Landrace barrows.

Greater breed differences in carcass traits were observed among the fall-farrowed breeds. Duroc, Hampshire, and Spot carcasses were similar in length and longer than carcasses of Pietrain barrows. Backfat at the 10th rib was thinnest for Hampshire and Spot carcasses, intermediate for Duroc carcasses, and thickest for Pietrain carcasses. Loin eye area was largest for Pietrain, however, followed by Hampshire, Spot, and Duroc.

Breed means for puberty traits were calculated by weighting each year equally. Among the spring-farrowed breeds, Landrace had the highest percentage of gilts cycling and Yorkshire and Chester White had the lowest percentage of gilts cycling. Swedish Landrace reached puberty 3 weeks earlier than Large White and Chester White and 5 weeks earlier than Yorkshire.

In the fall-farrowed breeds, Pietrain and Spot had a higher percentage of gilts cycling and were younger at puberty than Duroc and Hampshire.

Within the next 2 years, additional data will become available on performance of purebreds, the performance of multibreed populations relative to parental purebreds, and on the genetic relationships among economically important traits. Analysis and interpretation of such information should be useful to both swine seedstock producers and commercial swine producers in improving production efficiency.

Puberty and Estrus in Confinement-Reared Gilts

Ronald K. Christenson and J. Joe Ford[1]

Introduction

A successful swine-breeding unit is dependent upon the reproductive efficiency of the breeding herd. The swine producer must exercise a continuing effort to regulate the breeding unit if financial profit is to be a reality. Maintaining an optimum litter size at birth and increasing the efficiency of the breeding herd offer two good opportunities for assuring a productive swine unit. Because at least 25 to 30 percent of the sow herd is replaced by gilts each year, introducing gilts into the breeding herd is an important aspect of herd productivity. Reproductive efficiency depends on the proportion of gilts reaching puberty, continuing regular estrous cycles, and conceiving at first breeding. Rearing of gilts in total confinement units places the gilts in an environment different from their natural habitat. This environmental change, along with genetic change of swine as a result of selection for leanness, may have altered physiological and behavioral patterns of gilts resulting in reproductive problems often encountered in confinement. Therefore, the objectives of our research have been to characterize the reproductive problems associated with puberty and the continuation of regular estrous cycles in gilts reared in total confinement.

Several factors that influence puberty and the continuation of regular estrous cycles in gilts have been identified. Those factors are (1) breed, (2) confinement environment, (3) season of the year during sexual development, (4) boar exposure, (5) nutrition, and (6) disease. The first three factors will be discussed in this report. The latter three factors will not be discussed, but the importance of these factors to either a confinement or nonconfinement swine unit should not be overlooked.

Procedure

Gilts of several breeds and breed crosses from the MARC swine herd were used in a variety of experiments. Gilts were reared in total confinement facilities throughout the experimental periods except in experiment 2 where littermate gilts in two seasons were reared from 10 weeks of age in either nonconfinement (NC) or confinement (C). Gilts were maintained in groups of 9 to 16 gilts/pen except in a few experiments where gilts were housed individually to facilitate blood sampling from indwelling jugular catheters.

In a majority of the experiments, gilts were checked once daily for estrus from 5 to 9 months of age with a mature boar. Puberty was defined as the day of first estrus, and gilts showing estrus every 18 to 23 days were classified as having regular estrous cycles. Gilts not showing regular estrous cycles were classified as noncyclic. Reproductive organs from noncyclic gilts were examined at laparotomy or after slaughter, and further classification of reproductive problems was then determined.

The general feeding regime followed for these experiments was as follows: From weaning to 2.5 months of age, gilts were fed an 18-percent crude protein diet, and from 2.5 to 9 months of age, gilts were fed a 16-percent crude protein corn-soybean diet. Gilts were fed *ad libitum* until they reached an average weight of 195 lb after which they were fed 4 lb/gilt/day.

Breed

The influence of breed on puberty and the continuation of regular estrous cycles have been studied in two large groups of gilts in C (experiment 1) and C and NC (experiment 2). In experiment 1, we studied a total of 434 gilts of the Hampshire (89), Duroc (44), Yorkshire (119), Large White (114), and Swedish Landrace (68) breeds born in March and May. The percentage of gilts showing regular estrous cycles in relation to chronological age (months) is presented in Figure 1. Landrace gilts showed the greatest estrous activity between 5 and 7 months of age, and the percentage of Landrace gilts showing regular estrous cycles at 6 months of age was greater than that of Hampshire, Large White, Yorkshire, and Duroc gilts. Estrous activity for the five breeds of gilts had reached a plateau at 8.5 months of age, and the percentage of gilts showing regular estrous cycles was greater for Landrace, Large White, Hampshire, and Duroc gilts than for Yorkshire gilts. Among gilts that reached puberty, Landrace gilts were younger, Hampshire and Large White were intermediate, and Yorkshire and Duroc gilts were older than gilts of the other breeds (Table 1).

In experiment 2, a total of 410 Duroc, Hampshire, Yorkshire, and Swedish Landrace by Large White (L x LW) reciprocal-cross gilts were reared from 2.5 to 9 months of age in either a winter (October to April) or a summer (April to October)

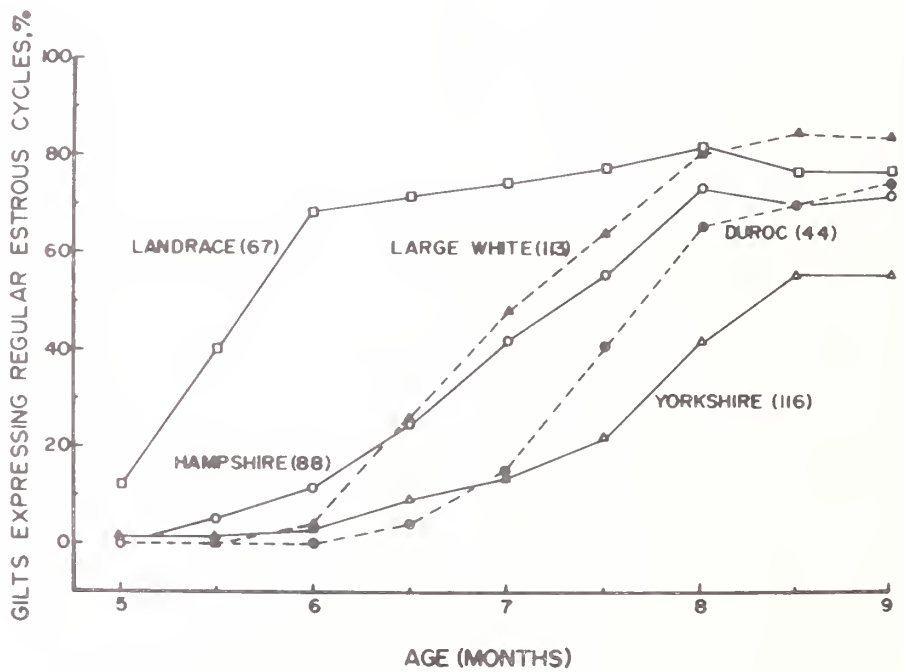

Figure 1—Estrous activity in relation to age of gilts reared in confinement. Total number of gilts in parentheses.

[1]Christenson is a research physiologist and Ford is the research leader, Reproduction Unit, MARC.

Table 1.—Reproductive status and age at puberty for gilts reared in confinement

Item	Swedish Landrace	Large White	Hampshire	Duroc	Yorkshire
No. of gilts	67	113	88	44	116
Reproductive status:[1]					
Gilts with delayed puberty --percent--	3.0	8.8	6.8	22.7	22.4
Behaviorally anestrous gilts --percent--	14.9	.9	13.6	2.3	17.2
Avg. age at puberty--days[2]--	[3]173 ± 3	[4]211 ± 2	[4]207 ± 3	[5]224 ± 3	[5]221 ± 3

[1]Gilts slaughtered at 9 months of age.
[2]Means ± standard error of the mean (SEM) for those gilts that showed estrus.
[3 4 5]Means without a common superscript differ ($P<0.01$).

season as per experimental design (table 2). Within each season, gilts were allotted to the experiment in two groups according to age (winter, period 1 and 2; summer, period 3 and 4). Within each period, littermate gilts were allotted by weight to either C or NC pens, with 16 to 18 gilts/pen.

Again, the breed of gilt influenced the percentage of cyclic gilts in C or NC at 7 and 9 months of age (Fig. 2). At 9 months of age, the percentage of cyclic gilts was highest among L x LW crossbred gilts, intermediate among LW x L crossbred and Hampshire gilts, and lowest among Yorkshire and Duroc gilts (Table 3). The average age at puberty for gilts reaching puberty by 9 months of age was lowest for LW x L and L x LW crossbred gilts, intermediate for Yorkshire and Hampshire gilts, and highest for Duroc gilts.

On the basis of these two experiments, the breed ranking changed only slightly for the Yorkshire and Duroc gilts. The percentage of Yorkshire gilts showing regular estrous cycles at 7 and 9 months of age increased, and the average age at puberty was reduced in experiment 2. In both experiments, estrous activity reached a plateau at 9 months of age, but the percentage showing regular estrous cycles was improved in the crossbred gilts of experiment 2 as expected. Thus, maintaining noncyclic gilts beyond 9 months of age for replacements cannot be recommended from an economic standpoint.

Table 2.—Experimental design

Housing	Breed[2]	Season[1]: October to April, Period 1	October to April, Period 2	April to October, Period 3	April to October, Period 4	Total
		No. of gilts				
Confinement	Duroc	9	5	7	8	
	Hampshire	7	7	12	30	
	Yorkshire	18	13	15	31	
	L x LW	13	4	9	7	
	LW x L	6	4	9	8	
		53	33	52	84	222
Nonconfinement	Duroc	9	5	8	9	
	Hampshire	6	8	12	11	
	Yorkshire	17	11	15	16	
	L x LW	12	4	9	9	
	LW x L	6	4	9	8	
		50	32	53	53	188
	Total	168		242		410

[1]Within each season, the oldest gilts (periods 1 and 3) were allotted to experiment approximately 3 weeks before the youngest gilts (periods 2 and 4).
[2]L x LW and LW x L were Landrace and Large White reciprocal-cross gilts.

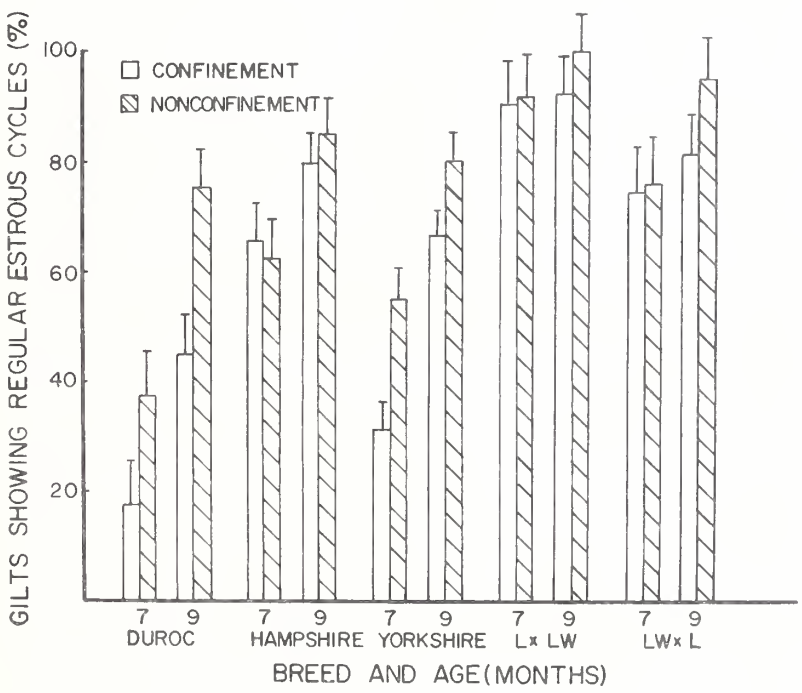

Figure 2—Percentages of cyclic gilts reared in confinement and nonconfinement relative to breed and age.

Delayed Puberty and Behavioral Anestrus

In experiments 1 and 2, noncyclic gilts at 9 months of age were slaughtered, and reproductive organs were examined (experiment 1, Table 1; experiment 2, Table 3). The majority of the noncyclic gilts were classified as gilts with delayed puberty and gilts with behavioral anestrus. Gilts with delayed puberty have undeveloped (immature) reproductive organs, and gilts with behavioral anestrus have fully developed, functional, reproductive organs but do not show behavioral estrus when they ovulate on a 21-day cyclic interval.

In experiments 1 and 2, the percentage of gilts with delayed puberty and behavioral anestrus is an economically significant percentage of the total number of gilts, and breed of gilt is significantly related to either one or both of the reproductive problems. Because of the significant percentage of behaviorally anestrous gilts observed in experiments conducted in to-

Table 3.—Influence of breed on estrous traits

Trait	Breed				
	Duroc	Hampshire	Yorkshire	L x LW[1]	LW x L[1]
Gilts at 9 months of age:					
No. of gilts	60	93	136	67	54
Cyclic, percent	[2]60.3 ± 5.2	[4]81.3 ± 4.6	[3]71.1 ± 3.5	[5]96.5 ± 5.0	[4]81.9 ± 5.7
Prepuberal, percent	[4]26.9 ± 3.2	[2]1.2 ± 2.9	[3]9.2 ± 2.2	[2]2.1 ± 3.1	[2].2 ± 3.5
Behavioral anestrus, percent	[2 3]4.4 ± 4.1	[3 4]13.4 ± 3.7	[4]17.4 ± 2.8	[2]1.4 ± 4.0	[4]16.4 ± 4.5
Other[10], percent	8.4 ± 2.4	4.1 ± 2.1	2.3 ± 1.6	0.0 ± 2.3	1.5 ± 2.6
Gilts that reached puberty:					
No. of gilts	43	80	103	65	50
Avg. age at puberty, days	[9]222.1 ± 4.4	[7]192.7 ± 3.4	[8]207.1 ± 2.7	[6]176.0 ± 3.4	[6]174.6 ± 4.0
Weight at puberty, lb	[3]227.5 ± 6.6	[3]199.8 ± 5.1	[2]207.7 ± 4.2	[23]214.7 ± 5.3	[23]214.9 ± 6.2

[1]Landrace (L) and Large White (LW) reciprocal-cross gilts.
[2 3 4 5]Means ± SEM without a common superscript differ (P<0.05).
[6 7 8 9]Means ± SEM without a common superscript differ (P<0.01).
[10]Others consists of 14 gilts who ovulated and/or showed estrus, initially, then stopped

Table 4.—Magnitude of behavioral anestrus and delayed puberty in gilts reared in confinement[1]

Breed[2]	No. of gilts	Month estrous checking initiated[3]	Age at slaughter	Behaviorally anestrous gilts	Gilts with delayed puberty
			(months)	pct	
D, H, Y	105	July	8.5	28.0	0.0
D, H, Y, LW, L	288	August	9.0	12.0	9.7
D, H, Y, LW, L	140	October	9.0	6.4	18.6
D, H, Y	78	April	12.0	28.0	2.6
D, H, Y	59	December	9.0	23.7	10.2
Y x (H x Y-D)[4]	18	June	8.0	11.0	38.9
H x Y-D[4]	79	October	12.0	10.0	0.0
L-LW[4]	27	December	9.0	7.4	3.7

[1]Trials conducted from 1976 through 1978.
[2]D—Duroc, H—Hampshire, Y—Yorkshire, L—Landrace, LW—Large White
[3]Daily estrous detection initiated at 145 to 165 days of age.
[4]Yorkshire and Duroc (Y-D) and Landrace and Large White (L-LW) reciprocal crosses

Table 5.—Estradiol benzoate (EB)-induced estrous response in anestrous gilts treated with or without methallibure before ovariectomy

Day of EB injection after ovariectomy	Estrous response to EB, percent[1]		
	Anestrous, methallibure (Group I)	Anestrous (Group II)	Cyclic, controls (Group III)
	(11)	(12)	(15)
Day 2	[2]90.9	[3]8.3	[2]93.3
Day 21	[2]100.0	[4]58.3	[2]93.3
Day 42	[2]100.0	[4]41.7	[2]93.3

[1]Number of gilts in parentheses.
[2 3 4]Means in the same column or row without a common superscript differ (P<0.01).

tal confinement (Table 4), the possibility that altered hormonal or adrenal (or both) activity may induce behavioral anestrus has been explored. Progesterone, luteinizing hormone (LH), cortisol, and estradiol-17β profiles during the period before, during, and after estrus, have been compared for behaviorally anestrous and contemporary cyclic gilts.

Progesterone, a steroid hormone capable of blocking estrus, was not elevated by abnormal adrenal function, and the concentration in the blood was similar in behavioral anestrous and normal cyclic gilts. Concentration of LH did not differ for behaviorally anestrous and cyclic gilts. Serum cortisol concentrations were greater in cyclic than behaviorally anestrous gilts (27 vs 21 ng/ml), but cortisol increased similarly at estrus in cyclic gilts and before ovulation in behaviorally anestrous gilts. Serum cortisol concentrations, therefore, do not explain the lack of estrous behavior in behaviorally anestrous gilts. The hormone estradiol-17β has been shown to be primarily responsible for estrous behavior in swine. Serum estradiol-17β concentrations were significantly greater in cyclic than behaviorally anestrous gilts before and during estrus, which may partially explain why behaviorally anestrous gilts do not show estrous behavior.

In another experiment, however, the estrous response of ovariectomized, behaviorally anestrous gilts induced by a fourfold higher dosage of estrogen than normally required, was only partially effective (Group II, Table 5). In addition, in this experiment, a hypothalamic-inhibiting drug (methallibure) was shown to be effective in reversing behavioral anestrus, and 90.9 percent of the behaviorally anestrous gilts (Group I) showed estrus as compared to 93.3 percent of the Group III control gilts (Table 5). In a subsequent experiment, pregnancy was achieved in 60 percent of behaviorally anestrus gilts treated with methallibure and pregnant

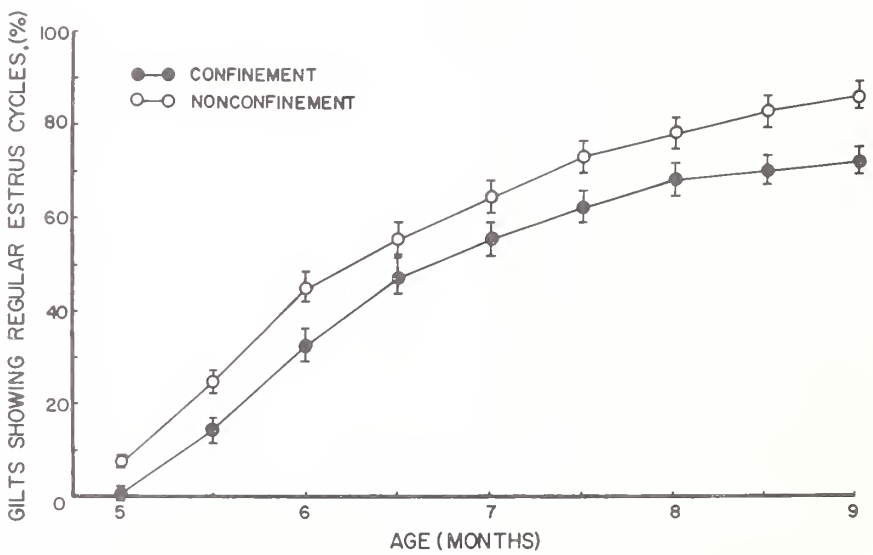

Figure 3—Percentages of cyclic gilts reared in confinement and nonconfinement relative to age.

mare serum gonadotropin. At this time, we are unable to explain why behaviorally anestrous gilts do not show estrus.

Confinement Environment

The shift from many small, nonconfined, swine production units to fewer, larger, total confinement units has either increased the reproductive problems in gilts or has increased our awareness of such problems. The confinement problem was addressed in the previously described experiment 2. The influence of C and NC rearing from 2 to 9 months of age on puberty and estrous traits in gilts is illustrated in Figure 3 and summarized in Table 6. Overall, the percentage of C gilts showing regular estrous cycles from 5 to 9 months of age was 12 percent lower than the percentage of NC gilts. Fewer C-reared than NC-reared gilts were cyclic at 9 months of age (71.3 vs 85.2 pct). The percentage of prepuberal gilts and behaviorally anestrous gilts at 9 months of age were higher among C than NC animals, and such data support industry concerns of greater puberty problems in C-reared gilts.

Photoperiod and social environment are two factors that are altered by C housing, and it has been suggested that these factors influence puberal development. In studies at the University of Nebraska and in Canada, however, the average age at puberty has been found to differ among gilts reared under different lengths of artificial daylight. These data suggest that length of daylight is not a major factor in the sexual development of C-reared gilts.

The social environment of C and NC rearing can influence estrous traits of gilts. Illinois and North Carolina researchers have reported that individual penning is more detrimental to puberal development than group penning. In fact, the general recommendation is to avoid extremes, small (individual) or large (25 to 50 gilts) groups of gilts/pen. Little is understood about the influence of social status (peck order social dominances) on the expression of estrus by closely confined gilts. Several trials were conducted to estimate the age at puberty in gilts reared from 3 to 8 months of age in pens with partly slatted floors; controls had an initial floor space of 4 ft^2/pig, and crowded gilts were restricted to one-half the space allowed to controls. Pen size was increased by 1 ft^2/pig when the average weight of each pen reached 75 lb/pig and at every 30-lb increase thereafter. The number of gilts reaching puberty and average age at puberty was not affected by crowding.

Table 6.—Influence of housing on estrous traits[1]

Traits	Housing	
	Confinement	Nonconfinement
Gilts at 9 months of age:		
No. of gilts	222	188
Cyclic, percent	[1]71.3 ± 3.1	[2]85.2 ± 3.1
Prepuberal, percent	[3]10.9 ± 1.9	[4]4.9 ± 1.9
Behavioral anestrus, percent	[3]14.6 ± 2.4	[4]6.6 ± 2.5
Other, percent	3.2 ± 1.4	3.3 ± 1.4
Gilts that reached puberty:		
No. of gilts	170	171
Avg. age at puberty, days	197.5 ± 2.4	191.4 ± 2.2
Weight at puberty, lb	217.6 ± 3.7	208.3 ± 3.3

[1 2]Means ± SEM without a common superscript differ (P<0.005)
[3 4]Means ± SEM without a common superscript differ (P<0.05).

Season of the Year during Sexual Development

Climatic conditions (season) influence the process of sexual development in gilts. In experiment 2, different percentages of gilts were observed to cycle when reared in the winter or summer seasons or periods within winter or summer. The percentage of cyclic gilts was highest in periods 1, 2, and 3 (Table 7). Gilts reared during period 3 averaged only 3 weeks older than gilts reared during period 4, but a significantly lower percentage of the gilts were cyclic at 9 months of age. This reduction in percentage of gilts showing regular estrous cycles at 9 months of age is attributed to the severity of seasonal temperatures that affected the gilts reared in period 4 more than the slightly older gilts reared in period 3.

Higher percentage of prepuberal and behaviorally anestrous gilts accounted for the lower number of cyclic gilts in period 4. Both C- and NC-reared gilts from period 4 had reduced estrous activity; however, the severity of the effect of season on sexual development was greater in C than NC. Collectively, high climatic temperatures (summer) appear to be more detrimental to sexual development than low climatic temperatures, and chronological and/or physiological age of gilt interact to affect the percentage of gilts showing regular estrous cycles.

In conclusion, breed of gilt, type of housing (C or NC), and specific climatic conditions of the season during sexual development all influence puberty and regularity of estrous cycles in gilts.

Table 7.—Influence of season on estrous traits[1]

Traits	Season			
	October to April		April to October	
	Period 1	Period 2	Period 3	Period 4
Gilts at 9 months of age:				
No. of gilts	103	65	105	137
Cyclic, percent	82.0 ± 4.2	80.6 ± 5.2	[1]84.7 ± 4.0	[2]65.6 ± 3.7
Prepuberal, percent	4.1 ± 2.6	7.1 ± 3.2	7.1 ± 2.5	13.4 ± 2.3
Behavioral anestrus, percent	12.8 ± 3.3	10.4 ± 4.1	[1] 2.5 ± 3.2	[2]16.7 ± 3.0
Other, percent	1.1 ± 1.9	1.9 ± 2.3	5.7 ± 1.8	4.3 ± 1.7
Gilts that reached puberty:				
No. of gilts	93	52	97	99
Avg. age at puberty, days	193.5 ± 2.9	201.4 ± 4.0	188.1 ± 2.8	195.0 ± 3.0
Weight at puberty, lb	213.6 ± 4.4	211.9 ± 6.2	216.0 ± 4.4	210.3 ± 4.6

[1 2]Means ± SEM without a common superscript differ (P<0.005).

Sexual Behavior of Boars

Donald G. Levis and Ronald K. Christenson[1]

Introduction

Low levels of sexual activity in breeding boars are a serious problem for many swine operations whether the breeding herd is confined or nonconfined. Sexual behavior (libido) is a factor that influences whether or not a boar will mate sows. It also affects the number of sows a boar will mate in a certain period. The problem is especially noticed when sows are hand mated because slow-serving boars are a nuisance.

Low levels of libido have a direct economic effect on a swine operation as well as an indirect effect through the overuse of more sexually active boars. Overworking sexually active boars leads to a decrease in litter size and farrowing rate.

Research information on measurements of libido in boars is limited. Therefore, the objectives of the following studies were to (1) develop a standardized testing procedure for evaluating libido in boars, (2) determine whether differences existed in libido between individually- or group-penned boars, and (3) evaluate the effects of libido by assisting boars with their first four matings.

Figure 1—Pretest familiarization period for the boar in the libido test pen with a tethered, estrous-induced, ovariectomized gilt in a separate pen within the test pen.

Procedure

Several preliminary libido tests were conducted with 8-month old boars having free access to an unrestrained, estrous gilt in a 12 ft x 12 ft pen. Because variation in the behavior of the estrous female (some would locate in a corner, making it difficult for a boar to make a rear mount), we decided to tether the females, positioning their head in a corner of the test pen. This allowed the boars to make a rear or side mount only.

Study I. In all studies, the boars were reared in all-male groups from 10 weeks of age until placed on these studies. Six pairs of full sib purebred Duroc boars were separated and allotted to either a group of three boars per 12 x 4 ft pen or as individual boar in a 4 x 4 pen at 6 months of age. When the boars were 8.5 months of age, they were evaluated for libido once/week for an 8-week period.

The libido test consisted of a 3-min pre-test familiarization period with the boar in the test pen with a tethered, estrous-induced, ovariectomized gilt in a separate pen within the test pen (Fig. 1). The boar was then allowed access to the gilt for 15 min (Fig. 2).

The courtship behavior traits evaluated for each boar in all studies were nose-to-nose contact, ano-genital sniffing, nosing the gilt's side, chanting by the boar, time to first mount, mounting gilt's side, mounting gilt's rear, and occurrence of successful mating. A successful ejaculation was designated as one lasting longer than 1.5 min.

Study II. Fourteen Duroc, Spot, and Hampshire boars were selected at 6 months of age and penned 4 to 6 boars per 12 x 32 ft pen. When the boars were 8.3 months of age, they were equally assigned to assisted or unassisted treatments, and boars were libido tested, as in Study I, after a 2-min familiarization period, twice/week (2 consecutive days) for 6 weeks.

Assisted boars were aided with intromission only during the first 2 weeks of libido testing. The boars were again libido tested twice/week for 4 weeks at 9.2 months of age and for 2 weeks at 12 weeks and 13.6 months of age.

Study III. Twenty crossbred boars were selected at 6 months of age and allotted to either a group of 4 boars per 6 x 12 ft pen or as an individual boar in a 2 x 7 ft stall. When the boars reached 8 months of age, they were evaluated for libido twice/week (2 consecutive days) for 3 weeks. The libido-testing procedure was the same as described for Study I.

Results

The standardized libido test procedure used in Studies I, II, and III was effective in determining sexual behavior in boars, and the procedure effectively reduced the variability generally created by estrous gilts. Two disadvantages of this and similar procedures are the facilities necessary for such tests and the time required for each test. In general, the most valuable trait recorded appears to be the occurrence of successful mating. The importance of the other courtship behavior traits will require further study. Successful mating is influenced by many factors, one being the boar's natural- or learned-mating dexterity. Mating dexterity definitely contributes to a high mating success, but this trait has proved to be difficult to quantitate.

Study I. Each boar was tested once/week for 8 weeks for a total of 48 tests for boars housed as a single and 48 tests for boars housed in a group. Mating success was significantly greater for boars housed in groups (26 completed matings, or 54.2 pct) than for boars housed individually (13

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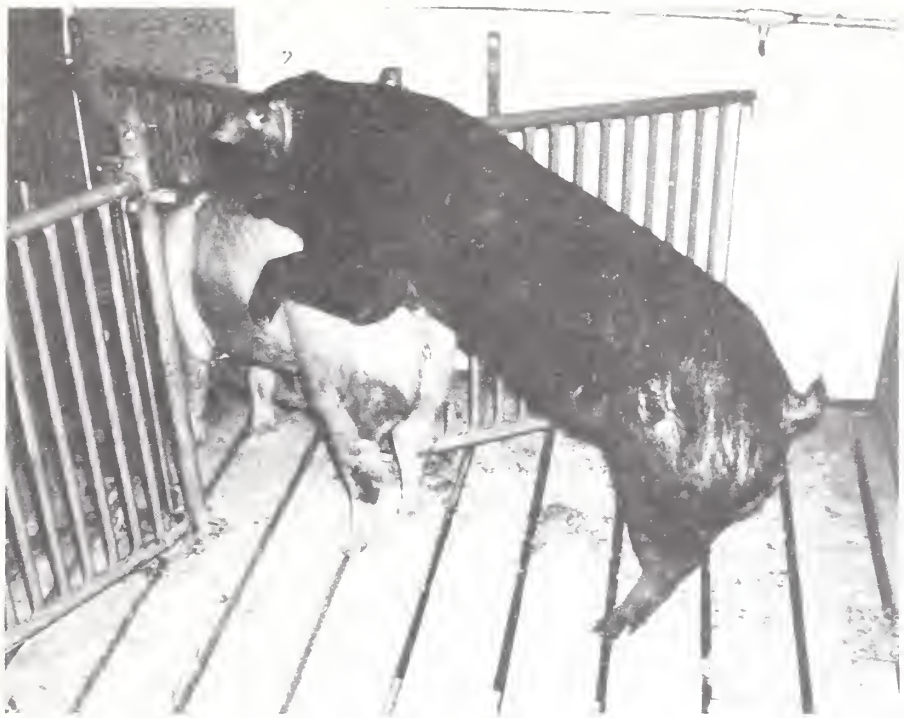

Figure 2—Boar mounting tethered, estrous gilt during libido test.

completed matings, or 27.1 pct) from 6 to 8.5 months of age (Table 1). Time to first mount, however, was similar for both treatments, and considerable variation was observed for boars of each treatment (Table 1). The elapsed time to first mount progressively decreased from 3.6 min (group boars) and 2.8 min (single boars) during the first four tests to 1.1 min during the last four tests for both single- and group-penned boars. Boars mounted an estrous gilt faster after a previous successful mating the week before than after a previous unsuccessful mating. Elapsed time to first mount, however, could not be used as a simple and reliable measure of mating success because of the wide variation in elapsed time to first mount for both successful and unsuccessful matings.

The average number of mounts/test was similar for boars housed individually or in a group (Table 1). As expected, a significant decrease in number of mounts was found when boars mated successfully than when mating was unsuccessful for both single- and group-penned boars. During unsuccessful matings, the boars did not give up easily as indicated by the average time to last mounting attempt and number of mounts (Table 1). Generally, when boars did not accomplish intromission within a few thrusts, they would dismount and try to realign themselves with the gilt before remounting.

The boar rank for number and percentage of successful mating is presented in Table 2. In general, the number and percentage of successful matings show that considerable variation exists for boars on the same treatment.

Study II. At the initiation of the libido-testing period (8.3 months of age), 14 boars were libido tested. Two boars assigned to the assisted treatment did not permit assistance, so were excluded from further analysis. Boars that were assisted with mating during the initial period (8.3 months of age) accomplished a 95-percent mating success whereas unassisted boars accomplished a 57.1-percent mating success during the same 2-week period. (Table 3). Successful mating results during the succeeding 4 weeks (9.2 months of age), at 12.0 and at 13.6 months of age, were not different for assisted and unassisted boars (Table 3). Under these experimental conditions, the 2-week assistance period (first four matings) did not improve mating success in subsequent libido tests.

The time to first mount and the average number of mounts/test for assisted and unassisted boars were similar and followed a similar pattern of that observed in Study I.

The boar rank for number and percentage of successful matings for boars in Study II is presented in Table 4 and suggests considerable variation for a group of boars.

Table 1.—Mating success and mounting performance for Duroc boars housed as singles or groups (Study I)

Item	Boars housed	
	Single	Group
No. of boars	6	6
Total no. of tests	48	48
Mating success, percent	[1]27.1	[2]54.2
Time to first mount, min	1.7	2.2
Avg. no. mounts/test	11.8	8.8
Avg. no. mounts for boars with:		
Successful mating	[3]5.0	[3]5.4
Unsuccessful mating	[4]14.3	[4]12.8

[1] [2]Significantly different ($P<0.01$) for single- and group-housed boars.
[3] [4]Significantly different ($P<0.01$) for successful and unsuccessful matings.

Table 2.—Boar rank for number and percentage of successful matings (Study I)[1]

Boar no.	Mating success	
	(no.)	(pct)
Single housed		
16205	4	50
17207	4	50
16405	2	25
18109	2	25
17803	1	13
16604	0	0
Group housed		
16203	7	88
17210	6	75
16605	4	50
17802	4	50
16407	3	38
18104	2	25

[1] Number of libido tests/boar was 8.

Table 3.—Mating success for assisted[1] and unassisted purebred boars (Study II)

Item	Assisted	Unassisted
No. of boars	5	7
Boar age: 8.3 months		
No. of tests	20	28
Mating success, percent	[2]95.0	[3]57.1
Time to first mount, min	.9	1.8
Boar age: 9.2 months		
No. of tests	40	56
Mating success, percent	67.5	58.9
Time to first mount, min	.4	.4
Boar age: 12.0 months		
No. of tests	20	28
Mating success, percent	60.0	60.7
Time to first mount, min	.5	.3
Boar age: 13.6 months		
No. of tests	16	24
Mating success, percent	75.0	75.0
Time to first mount, min	.3	.5

[1] Assistance was provided only during tests at 8.3 months of age.
[2] [3]Significantly different ($P<0.005$) for assisted and unassisted boars.

Table 4.—Boar rank for number and percentage of successful matings for boars at 9.2, 12, and 13.6 months of age (Study II)[1]

Boar no.	Mating success	
	(no.)	(pct)
Assisted		
34107	14	88
36005	11	69
39906	11	69
39209	8	50
[2]33904	7	44
Unassisted		
44306	14	88
36305	13	81
33506	13	81
35303	11	69
35004	8	50
[3]38904	6	50
39005	3	19

[1]Number of libido tests/boar was 16.
[2]Boar had no successful mating (0/4) at 13.6 months of age; boar was lame.
[3]Boar died before 13.6 months of age; data were based on 12 libido tests.

Table 6.—Boar rank for number and percentage of successful matings (Study III)[1]

Single-housed			Group-housed			
Boar no.	Mating success		Group no.	Boar no.	Mating success	
	(no.)	(pct)			(no.)	(pct)
40807	6	100	1	42808	6	100
39910	5	83		40208	6	100
44710	5	83		41310	4	67
46508	5	83		46911	1	17
46907	5	83	2	50506	6	100
50310	5	83		46506	6	100
49706	3	50		44405	4	67
42505	2	33		49705	1	17
			3	42504	6	100
				43210	3	50
				50006	3	50
				49908	2	33

[1]Number of libido tests/boar was 6.

Table 5.—Mating success and mounting performance for crossbred boars housed as singles or groups (Study III)

Item	Boars housed	
	Single	Group
No. of boars	8	12
No. of observations	48	72
Mating success — percent	75.0	66.7
Time to first mount — min	1.2	.7
Avg. no. mounts/test	5.5	4.3
Avg. no. mounts for boars with:		
Successful mating	3.5	3.8
Unsuccessful mating	[1]11.6	[2]5.3

[1] [2]Significantly different ($P<0.05$) for single- and group-housed boars.

Study III. Mating success for crossbred boars housed as individuals or groups from 6 to 8 months of age was not different and averaged 75 vs 66.7 percent, respectively, in this study (Table 5). The reason for the improvement in mating success in Study III as compared with Study I is most likely due to the overall improvement of sexual behavior observed for the crossbred boars. Time to first mount and average number of mounts/test, again, followed the same pattern as observed in Studies I and II.

Table 6 shows the boar rank and percentage of successful matings in Study III. Boars housed as singles ranged from two of six to six of six successful matings/libido test. This points out the occasional boar with low sexual activity encountered frequently in the swine industry.

In the group-housed boars, a definite pattern appeared to be set. In all three groups, there were one or two sexually active boars and one boar with low sexual activity.

In conclusion, a satisfactory procedure was developed for estimating the sexual behavior of boars. The occurrence of a successful mating in the time allowed was the single most important factor used in measuring sexual behavior in the boars. An additional measurement, not employed in this experiment, would be to determine the number of successful matings a boar could achieve during the 15-min test. This could be accomplished by providing additional estrous gilts immediately after a completed mating.

The relative importance of the other courtship behavior traits still needs to be assessed by their correlation to mating success during the libido test.

Sexual Development and Puberty of Boars

Rodney D. Allrich, Ronald K. Christenson, J. Joe Ford, and Donald D. Lunstra[1]

Introduction

The boar constitutes an important element in the swine industry. In common swine production practice, the boar breeds many females over a year's time while an individual female will produce only one to two litters during this period. Accordingly, a boar with suboptimal or low fertility has greater economic impact on productivity than a female with similar characteristics.

Identification and characterization of the hormonal and morphological changes relative to testicular function must be thoroughly studied to fully understand how to optimize the management from birth to herd sire. Relatively little is known about the relationships of hormones and testicular morphology of the boar and about the mechanisms that are responsible for testis growth and function. Many factors may influence the pubertal development of the boar. These factors include type of housing, season, nutrition, photoperiod, social interactions, breed, disease, and other unidentified factors. Information concerning pubertal development of the boar would benefit both the swine producer and animal researcher.

The objectives of this research were to characterize hormone profiles of testosterone (T), estradiol-17β (E_2), cortisol (C), and luteinizing hormone (LH) during pubertal development of the boar. Morphological changes of the testis, T and E_2 production after *in vitro* stimulation, and LH release after castration were characterized.

Procedure

Forty-eight Landrace X Duroc boars were reared under standard management conditions in a total confinement environment. Boars were born within a 3-week period during the spring, weaned at 4 weeks of age, and maintained in a nursery in boar-only groups until 10 weeks of age. Boars were then moved to a modified-open-front (MOF) type of finishing building and penned in groups of 16. Boars remaining at approximately 150 days of age were moved to individual stalls. Corn-soybean meal diets containing 18-, 16-, and 14-percent protein were fed to boars in the nursery, MOF, and stalls, respectively. *Ad libitum* feeding was practiced until boars were moved to individual stalls, at which time feed was reduced to 6 lb daily. Boars were exposed to 12 h of artificial light daily in the farrowing house and nursery and 16 h of artificial light daily through the remainder of the experiment.

At weaning, the boars were randomly allotted to eight castration ages (40, 70, 100, 130, 160, 190, 220, and 250 days). Five days before (−5) scheduled castration, catheterization of the external jugular vein (medical tubing placed in vein) was performed so frequent blood samples could be taken from the boar with little or no stress. At castration, anesthesia was induced and maintained with an injectable anesthetic. Testes and epididymides were promptly removed, trimmed of excess tissue, and weighed. Blood samples were taken every half hour between 0800 and 1200 h 2 days before (−2) and on days +1, +2, +3, +4, +8, and +16 after castration. Blood samples were processed, and the serum fraction pipetted and stored at −20°C until samples could be assayed (by radioimmunoassay) for hormone content.

Within 15 min after castration, the tissue of the right testis was dissected free and randomly cut into 0.5-g pieces, which were minced in separate flasks containing a specially defined media. A hormone (human Chorionic Gonadotropin, hCG), which acts like LH, was then added to stimulate testicular tissue to produce and release T and E_2. The quantities of T and E_2 were determined for all boars.

In addition, the entire left testis was immediately injected, via the testicular artery, with a fixative that preserved the tissue so that it could be examined (after sectioning and staining) with a microscope. Using this approach, morphological changes occurring within the testis during pubertal development were evaluated.

Results

Body weights and paired weights of testes and epididymides increased throughout the period from 40 to 250 days of age (Table 1). Body, testes, and epididymides weights would be expected to continue increasing (at a slower rate, however) through at least 1 to 2 years of age. Our study indicated that sire influenced both testes and epididymides weights. Within age group, there were no significant correlations between body weights and paired testes or epididymides weights, indicating that body weight is not a primary factor controlling testes growth. In other words, at any given age, the largest boar will not always have the largest testes and vice versa.

Table 1.—Body weights, paired testes and epididymides weights, and total weight and total number of Leydig cells per paired testes of boars between 40 and 250 days of age

Age	No. of boars	Body weight	No. of boars	Testes weight	Epididymides weight	Total weight of Leydig cells	Total number of Leydig cells
(days)		(lb)		(g)			($X 10^{-9}$)
40---------	48	[1]19.1 ± 0.7	6	8.2 ± 1.1	2.8 ± 0.2	3.3 ± 0.4	1.7 ± 0.2
70----------	42	49.5 ± 1.3	6	21.9 ± 2.4	8.5 ± 1.1	9.8 ± 1.1	5.2 ± .3
100----------	36	91.1 ± 1.5	6	49.1 ± 5.1	20.3 ± 1.2	18.7 ± 1.9	13.7 ± 2.2
130----------	30	145.2 ± 2.6	6	202.9 ± 23.5	42.0 ± 2.9	47.4 ± 5.5	23.2 ± 3.9
160----------	24	198.0 ± 4.2	6	407.7 ± 49.2	78.8 ± 5.6	79.9 ± 9.6	23.8 ± 3.6
190----------	18	239.4 ± 3.5	6	564.5 ± 36.3	121.9 ± 4.6	77.9 ± 5.0	44.0 ± 6.3
220----------	12	257.2 ± 4.0	6	612.8 ± 34.9	143.2 ± 8.0	61.2 ± 3.4	55.0 ± 2.5
250----------	6	270.6 ± 4.8	6	638.5 ± 43.9	147.2 ± 5.6	67.6 ± 4.7	56.0 ± 4.2

[1]Data presented are means ± standard error of the mean.

Testosterone concentrations increased between 40 and 220 days of age before declining sharply at 250 days (Fig. 1). The mechanism responsible for the increasing concentrations of T during pubertal development and the decline in T concentrations at 250 days can only be

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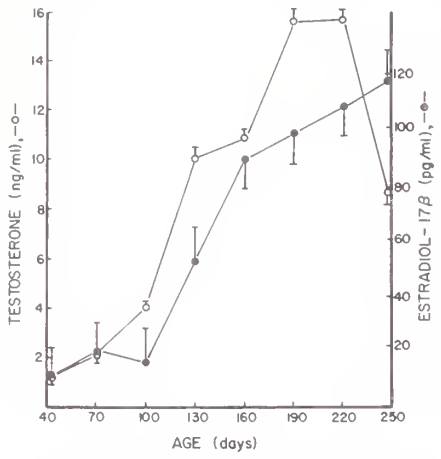


Figure 1—Profile of mean (± SEM) serum testosterone and estradiol-17β concentrations in boars between 40 and 250 days of age.

theorized. As the boar develops, testes weight increases, thereby providing for the presence of a larger mass of Leydig cells and seminiferous tubules. Research shows that sensitivity of Leydig cells to gonadotropins may increase during pubertal development. The increased mass and sensitivity of Leydig cells may, in turn, produce greater quantities of steroids resulting in higher serum concentrations of T.

The profiles of E_2 concentrations remained constant through 100 days of age and increased steadily thereafter (Fig. 1). Serum E_2 concentrations did not decline at 250 days as did T concentrations. One possible explanation for sustained levels of E_2 is that a shift in metabolism occurs in the testes, thereby allowing E_2 secretion to continue in the face of declining T concentrations. The function of E_2 in male reproductive physiology is not known, but a role in sexual behavior and testicular T synthesis has been suggested. In the boar, researchers have concluded that E_2 acts synergistically with T on accessory sex glands and sexual behavior. Serum concentrations of E_2 were influenced by sire, indicating that sire may alter hormonal patterns in pigs.

Cortisol displayed a distinct drop in concentration (to 10 ng/ml) at 100, 130, and 160 days of age (Fig. 2). Serum C was monitored in the present experiment because increases in adrenal steroid secretion are associated with increases in testicular steroid secretion in boars. No such association was apparent in the present study.

A slight, but not significant, elevation in serum LH concentration occurred at approximately the time of greatest testicular growth (Fig. 2). Serum LH is partially responsible for growth of the testes and increasing concentrations of T and E_2 present during pubertal development.

The existence of an operative negative feedback mechanism controlling LH was assessed by evaluating LH concentrations before and after castration. Through 160 days of age, a negative feedback mechanism was operating and evidenced by elevated LH concentrations 1 to 2 days after castration. This response was absent after 160 days of age and indicates that a decrease in the sensitivity of the negative feedback mechanism may have occurred. This finding indicates that additional LH stimulation may occur during pubertal development in the face of increasing steroid hormone concentrations. If this decrease in sensitivity did not occur, pubertal development may be delayed.

The present study demonstrates an enhanced steroidogenic response, as measured by increased T and E_2 production, by testicular tissue *in vitro* to hCG stimulation during pubertal development. Testosterone production per Leydig cell and E_2 production per 500 mg of testicular tissue increased at all hCG dosages at 130 and 160 days of age, indicating that this period in the life of the boar may be important in determining potential steroid production.

Testicular volume percentage of seminiferous tubules and tubular diameters increased with age of boar (Fig. 3 and 4). The largest increase occurred between 100 and 130 days of age. At this time, the testes first release sperm into the duct system for eventual transport during ejaculation. All boars examined at 130 days of age and beyond had sperm present in the seminiferous tubule lumen.

Volume percentage of Leydig cells (Fig. 5) in the testes during pubertal development had a reverse trend, compared with seminiferous tubules. Maximal values (45 pct) of volume percentage of Leydig cells in the testes occurred at 70 days of age and declined steadily to 10 percent at 220 days of age. Because of immense testis growth, however, the total number of Leydig cells (Table 1) generally increases through pubertal development. However, the total weight of Leydig cells (Table 1) appeared to reach maximum values at 160 days of age and declined slightly thereafter. Leydig cell volume (Fig. 5) was also evaluated and found to fluctuate randomly during development; however, at 160 days of age, a large increase in Leydig cell volume occurred. The exact cause of this increase is not readily apparent, but it may relate to hormone production activity of the cells.

In conclusion, this study has shown that testicular growth is rapid between 100 and 190 days of age in the boar. This growth was the result of profound morphological structural alterations that included increases in seminiferous tubule diameter, and most likely length, as well as increases in total number of Leydig cells. Serum concentrations of T and E_2 also increased at this time, suggesting that this time period (days 100 through 190) is critical for the development of the boar. Additional studies are needed to evaluate the influence of nutrition, housing, social environment, photoperiod, temperature and many other factors on the hormonal profiles and testicular morphology.

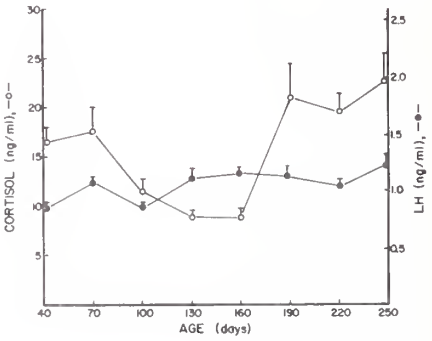


Figure 2—Profile of mean (± SEM) serum cortisol and LH concentrations in boars between 40 and 250 days of age.

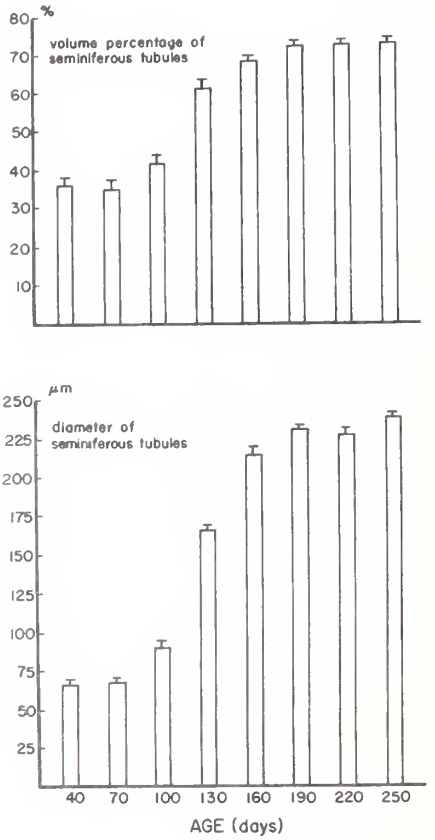
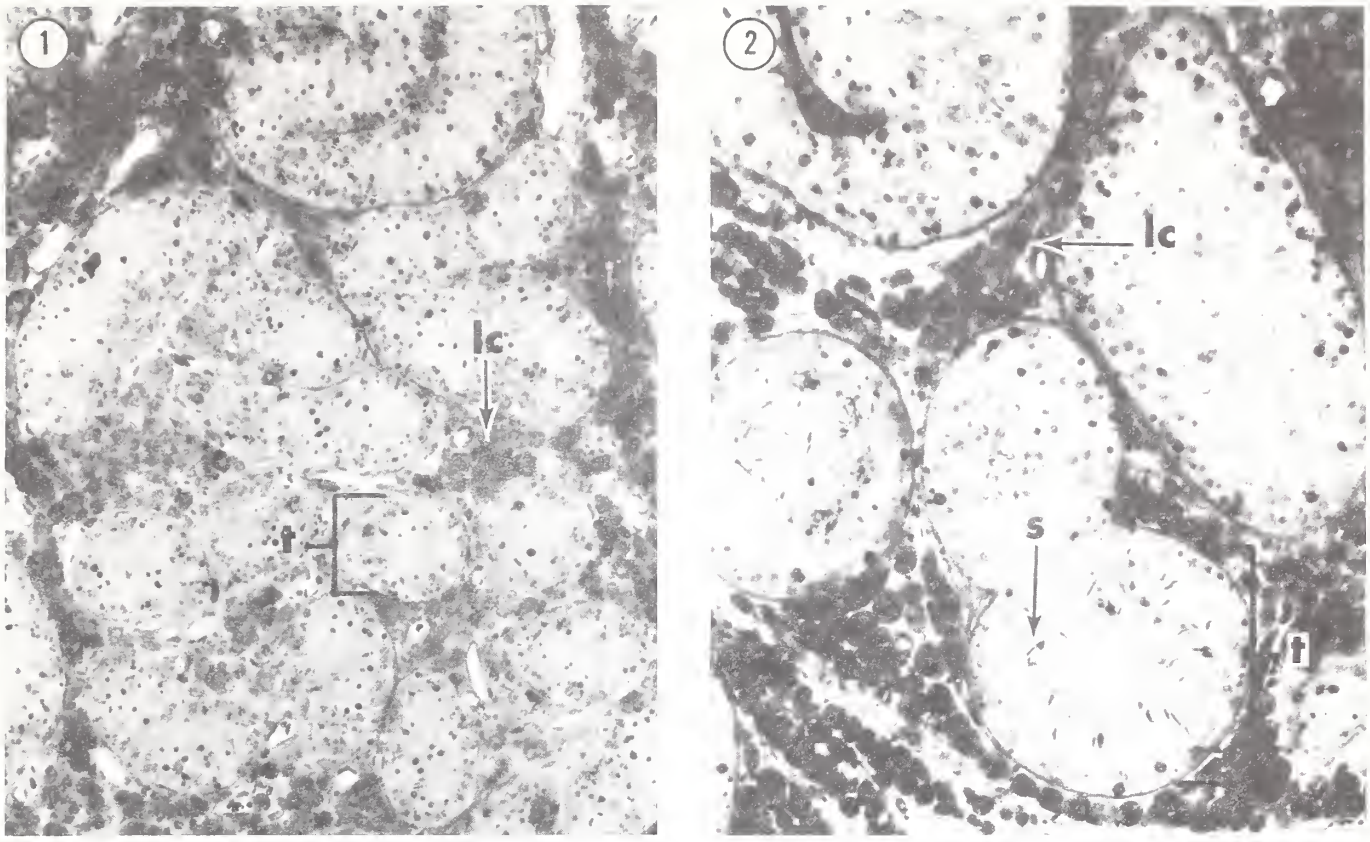


Figure 3—Testicular volume percentage (± SEM) and diameter (± SEM) of seminiferous tubules of boars between 40 and 250 days of age.



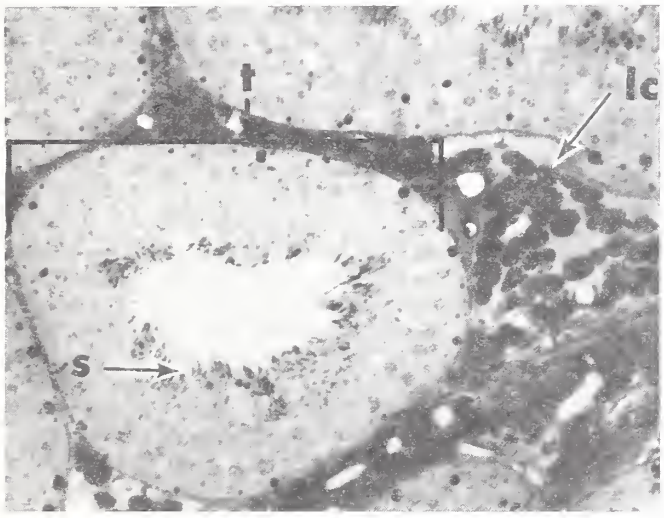


Figure 4—Photomicrographs (magnification=640) of boar testicular tissue (t=seminiferous tubule; lc=Leydig cell; s=sperm) at (1) 40 days of age, (2) 130 days of age, and (3) 220 days of age.

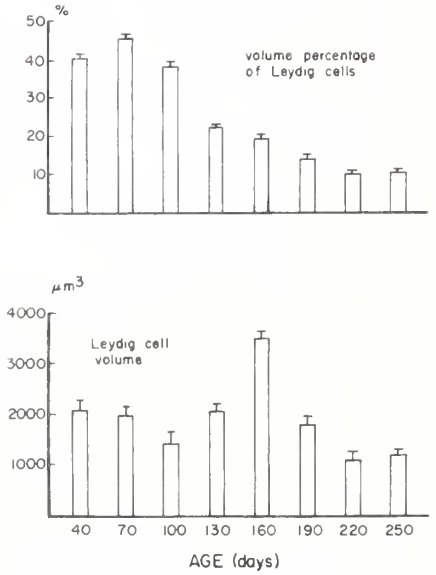


Figure 5—Testicular volume percentage (± SEM) and volume (± SEM) of Leydig cells of boars between 40 and 250 days of age.

Contribution of Testosterone and 5α-Androstenone to the Incidence of Boar Taint in Pork Meat

Bruce D. Schanbacher, Wilson G. Pond, Steven C. Seideman, and Jong-Tseng Yen[1]

Introduction

Castrating male pigs is common practice at a few days or weeks of age to prevent the later development of objectionable odors and flavors in pork. This practice carries with it a compromise in reduced rate of weight gain and efficiency of feed utilization and increased carcass fat. A substantial improvement in overall swine production economy and biological efficiency would result from marketing intact male pigs void of boar taint (objectionable odor).

The pheromone most closely associated with boar taint, 5α-androstenone, appears to be produced within the testes and secreted into the systemic circulation in response to gonadotropic stimulation. A positive relationship, therefore, exists between the secretion of 5α-androstenone and the principal testicular hormone, testosterone (T). While the anabolic nature of T is well founded, its contribution to peripherally derived 5α-androstenone and other compounds associated with objectionable male odors remains unknown. The following studies were conducted to determine whether T administration might induce boar taint or other objectionable odors in barrows.

Procedure

Forty-eight male pigs (4 each from 12 litters) were assigned at birth to one of two experiments. Experiment I comprised 32 pigs (8 litters), whereas experiment II comprised the remaining 16 pigs (4 litters). For each experiment, littermates were randomly assigned to one of four treatment groups. Group 1 pigs were left as intact boars, group 2 pigs were castrated at birth, group 3 pigs were castrated at approximately 100-lb body weight, and group 4 pigs also were castrated at 100-lb body weight but simultaneously given T (exp. I) or testosterone propionate (TP) (exp. II) replacement therapy. Hormone replacement therapy was provided by five subdermal steroid-filled polydimethylsiloxane (Silastic) capsules. In preliminary experiments, these capsules were shown to provide threshold (T) and near-normal (TP) circulating levels of androgen to growing-finishing barrows.

Litters were weaned at 4 weeks of age and subsequently placed in individual feeding pens, where they were maintained until slaughtered at 240 lb. All pigs were fed a 16-percent protein corn-soybean grower diet *ad libitum* for the duration of the study, and periodic blood samples were collected to form a serum pool for each pig. Selected carcass traits and accessory sex gland weights were collected and recorded at slaughter. A loin chop with external fat also was collected and subsequently analyzed by consumer taste panel for incidence of boar taint.

Results

Performance responses of male pigs to castration and T replacement therapy are presented in Table 1. Although considerable inter- and intra-litter variation in performance traits were shown to exist, part of the differences between performance data of experiments I and II can be attributed to (1) breed effect (exp. I, Yorkshire vs exp. II, crossbred), (2) year effects (exp. I, 1980 vs exp. II, 1982), and (3) time of slaughter (exp. I, constant weight vs exp. II, constant age).

Neither castration nor T treatment significantly affected growth rate or final weight in these studies even though the intact boars in experiment I tended to reach slaughter weight earlier than their castrate littermates, and the intact boars in experiment II tended to be heavier than their castrate littermates at the time of slaughter. Similarly, boar carcasses tended to be longer than those of their castrate littermates but not significantly so. The most significant treatment effect, which was observed in both experiments, was that of reduced loin eye area and increased backfat thickness following castration. This castration effect was generally reversed by T treatment.

The ability of T to reverse the castration effects on growth and performance in pigs is contingent on the ability of the replacement regimen to provide physiological concentrations of T. This requirement was met by the TP implant used in experiment II but was only marginally successful with the T implant used in experiment I (Table 2). The similarity of serum T concentrations in boars and barrows implanted with TP and the marked stimulation of the accessory sex gland weights by both experimental implants suggest that T can be replaced to the castrate male pig at physiological dosages using steroid-filled Silastic capsules.

In view of this achievement, our objective to assess the relative contribution of T to the incidence of boar taint seems appropriate. The consumer panel detected objectionable odors or boar taint (or both) in both fat and lean tissue from all boar carcasses although only three of eight (exp. I) and none of four (exp. II) were strongly objectionable. In contrast, boar taint was not detected in any of the implanted barrows, and the presence of objectionable odor was rated only slight or nondetectable.

Thus, T, when administered to the castrate male pig at a physiological dose, appears not to cause an increased incidence of boar taint. This finding suggests that the anabolic effects of T are dissociated from the boar taint effects of 5α-androstenone. Furthermore, these data suggest that a commercial implant with anabolic activity might be developed for pigs without concern for odor-related consumer rejection. Alternatively, pork production might be improved by marketing boars treated with specific inhibitors of 5α-androstenone synthesis.

[1]Schanbacher is a research physiologist, Reproduction Unit; Pond is the research leader, Nutrition Unit; Seideman is a research food technologist, Meats Unit; and Yen is a research animal scientist, Nutrition Unit, MARC.

Table 1.—Growth rate, feed utilization, and carcass traits of boars, barrows, and barrows given testosterone (exp. I) or testosterone propionate (exp. II)

Group	Avg. daily gain	Feed/gain	Final wt	Carcass wt	Carcass length	Backfat last lumbar	Loin eye area
	(lb/d)	(lb/lb)	------- (lb) --------		---------- (in) ----------		(in^2)
Experiment I:							
Boars	1.80	2.54	236	NR	33.1	[3]0.63	[3]6.81
Barrows[1]	1.65	2.82	239	NR	32.0	[3 4].91	[4]6.10
Barrows[2]	1.75	2.51	239	NR	32.3	[4].98	[4]6.29
Barrows + T	1.65	2.66	233	NR	33.2	[3 4].79	[3]6.94
Experiment II:							
Boars	2.07	[3]3.02	257	185	33.4	[3].95	[3]5.60
Barrows[1]	1.88	[4]4.35	241	177	32.2	[4]1.41	[4]4.34
Barrows[2]	2.00	[3 4]3.68	253	150	32.7	[4]1.23	[4]4.13
Barrows + TP	1.81	[3]3.45	227	159	32.1	[3 4]1.11	[4]4.35

[1]Castrated at birth.
[2]Castrated at approximately 100-lb liveweight. Testosterone (T) or testosterone propionate (TP) was administered via Silastic implants at the time of castration.
[3 4]Means without a common superscript within column differ ($P<0.05$).
NR = not recorded.

Table 2.—Serum testosterone, accessory sex gland weights, and incidence of objectionable odors (boar taint) in boars, barrows, and barrows given testosterone (exp. I) or testosterone propionate (exp. II)

Group	Serum testosterone	Seminal vesicle	Prostate	Bulbo-urethral	Boar taint[3]	
					Fat	Lean
	(ng/ml)	---------- (g) ----------				
Experiment I:						
Boars	[4]3.25	[4]307	[4]10.1	[4]194	[4]4.4	[4]3.4
Barrows[1]	[5].12	[5]2	[5]6	[5]9	[5]2.3	[5]2.2
Barrows[2]	[5].16	[5]5	[5].8	[5]18	[5]2.5	[5]1.8
Barrows + T	[6].55	[4]195	[6]5.6	[5]116	[5]2.9	[5]2.0
Experiment II:						
Boars	[4]3.75	[4]153	[4]7.2	[4]164	4.0	2.4
Barrows[1]	[5].11	[5]2	[5].5	[5]10	3.7	2.6
Barrows[2]	[5].18	[5]4	[5].7	[5]14	3.5	2.2
Barrows + TP	[4]4.81	[6]513	[4]11.5	[6]243	3.5	2.7

[1]Castrated at birth.
[2]Castrated at approximately 100-lb liveweight. Testosterone (T) or testosterone propionate (TP) was administered via Silastic implants at the time of castration.
[3]1 = no objectionable odor, 2 = trace of odor, 3 = slight odor, 4 = distinct odor, 5 = strong odor, 6 = very strong odor.
[4 5 6]Means without a common superscript within column differ ($P<0.05$).

Differentiation of Sexual Behavior in Swine

J. Joe Ford, Ronald K. Christenson, and Ralph R. Maurer[1]

Introduction

Studies on sexual behavior in swine are required to reduce production costs that result from boars that show little or no interest in mating with estrous sows and with females that ovulate but fail to show estrus. From studies conducted on other animals, we know that during prenatal and postnatal development, animals go through maturational stages during which they are sensitive to steroid hormones (estrogen and testosterone). During these stages, exposure to estrogen or testosterone causes changes in brain development that affect sexual behavior when animals reach adulthood. Initially, animals of either sex possess behavioral traits characteristic of females unless they are exposed to testosterone or estrogen during these sensitive maturational stages. Sexual differentiation from female to male traits results in loss of female behavior in boars as they develop from conception through puberty. From studies in other animals, we would predict that the sensitive stage for differentiation of sexual behavior in pigs would occur prenatally.

The timing of anatomical changes associated with sexual differentiation in pigs is well characterized. Although the sex of a pig is determined at conception, males and females are similar anatomically through day 25 of pregnancy. On day 26 of pregnancy, testicles begin to form in male embryos, and by day 40 of pregnancy, the scrotum is formed. At this time, males are easily distinguished from females. These anatomical changes form the basis for anticipating when behavioral changes would be expected to occur.

The objectives of our research are to define when steroid-sensitive periods occur in pigs and to determine if optimization of testicular development during these sensitive stages will improve sexual behavior in boars. In the first study, we determined the pattern of testosterone secretion in pigs during pregnancy. In the next two studies, loss of estrous behavior was evaluated in boars castrated at different ages during postnatal development. Two traits that were examined and that are readily observed in estrous sows were attraction toward mature boars and display of an immobilization response, which allows a boar to mount. The fourth study evaluated estrous behavior in gilts that were masculinized with testosterone during prenatal development.

Procedure

Experiment 1. On different days of pregnancy, gilts were anesthesized and serum was obtained from the umbilical artery of fetuses. Serum testosterone concentrations were determined on these sera by radioimmunoassay.

Experiment 2. Littermate boars were castrated at 0.5 or 8 months of age. Littermate gilts were ovariectomized at 8 months of age and, after 9 months of age, pigs were treated with estrogen at three different dosages to evaluate their sensitivity to estrogen.

Experiment 3. Littermate boars were castrated within 48 h of birth or at 2, 4, 6, or 8 months of age and treated with estrogen at 9 months of age. Littermate gilts were ovariectomized after puberty and treated with estrogen simultaneously with the barrows. The occurrence of the immobilization response was recorded. At 11 months of age, barrows that resulted from castration within 48 h of birth, or at 4 or 8 months of age, and ovariectomized gilts were treated with estrogen, and their attraction to mature boars was evaluated. This was accomplished by individually placing each castrated pig into a rectangular pen. A mature male was penned in an adjacent gestation stall at one end of the rectangular pen, and a mature gilt was penned in another adjacent gestation stall at the other end of the rectangular pen. View of the mature boar or gilt in the gestation stall was achieved by the test animal by moving from one end to the other of the rectangular pen. On days 3 and 4 after treatment with estrogen or treatment with cottonseed oil alone as a control, the amount of time each test pig spent in the male end of the rectangular pen was recorded.

Experiment 4. Pregnant sows were treated with cottonseed oil alone as a control or testosterone propionate (in cottonseed oil) on days 29, 31, 33, and 35 of pregnancy or on days 39, 41, 43, and 45 of pregnancy. Gilts produced from these sows were checked for estrus once daily from 7 to 9 months of age to determine if they reached puberty and if they showed regular estrous cycles.

Results

Experiment 1. Serum testosterone concentrations in males were low on day 30 of pregnancy, increased sharply by day 35, and then declined thereafter (Fig. 1). Testosterone was not detected in the serum of females at any time during pregnancy.

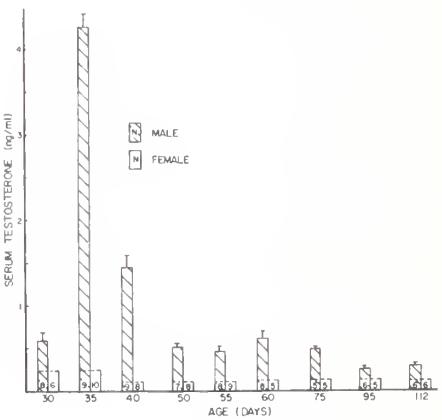


Figure 1—Concentrations of testosterone in umbilical arterial serum of embryonic and fetal pigs. Dashed line indicates minimum sensitivity of the assay. Numbers at base of each bar indicate number of embryos or fetuses sampled on each day.

Experiment 2. Barrows resulting from castration at 0.5 months and ovariectomized gilts showed the immobilization response (estrus) after estrogen was injected (Fig. 2). The minimum effective dosage of estrogen required to induce immobilization in 100 percent of the pigs within these two groups was 1.14 μg/lb of body weight, and the duration of estrus (days) increased as dosage of estrogen increased. Barrows resulting from castration at 8 months of age showed little female estrous behavior after estrogen treatment.

Experiment 3. The proportion of barrows treated with estrogen that showed immobilization decreased as age at castration increased (Fig. 3). The duration of estrus (days) also decreased as age at castration of barrows increased. Barrows that were castrated at 4 months of age showed a positive response to estrogen but a short duration of estrus. Barrows resulting from castration within 48 h of birth or at 2 months of age were similar to gilts in their responses to estrogen treatment.

[1]Ford is a research physiologist and the research leader, and Christenson and Maurer are research physiologists, Reproduction Unit, MARC.

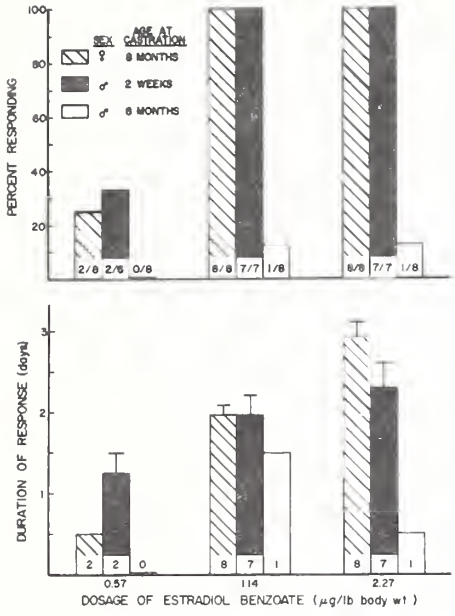


Figure 2—Immobilization response in gonadectomized pigs after different dosages of estradiol benzoate.

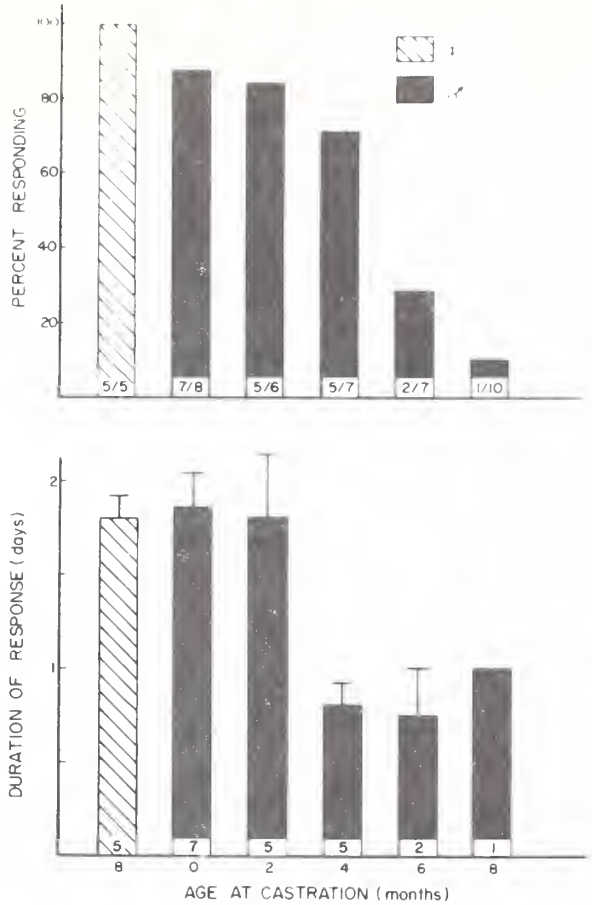


Figure 3—Immobilization response in barrows that were castrated at different ages and ovariectomized females. Dosage of estradiol benzoate was 1.14 µg/lb of body weight.

Barrows that were castrated at birth and ovariectomized gilts spent more time near the mature boar after estrogen treatment than after treatment with cottonseed oil (Fig. 4). This increase in time spent in the boar end of the test pen was not observed after estrogen treatment of barrows that were castrated at 4 or 8 months of age.

Experiment 4. Gilts that were farrowed by sows treated with testosterone propionate from days 29 to 35 of pregnancy had a preputial orifice on their underline instead of a vulva. Gilts from sows treated with testosterone propionate from days 39 to 45 had a vulva with an enlarged clitoris. Normal appearing ovaries and uteri were present in both of these groups of gilts. Boars were not affected anatomically by treatment as expected. The majority of gilts from sows treated with testosterone propionate were having regular estrous cycles by nine months of age (10/10 for control gilts; 9/10 for gilts from sows treated from days 29 to 35; 6/8 for gilts from sows treated from days 39 to 45).

The testes of male pig fetuses actively secrete testosterone on day 35 of pregnancy, and treatment of pregnant sows with testosterone around this time causes masculinization of female fetuses. Attempts to tie differentiation of sexual behavior to prenatal testosterone secretion, however, were unsuccessful. Boars castrated before 2 months of age showed behavior that was characteristic of females instead of males; thus, differentiation of sexual behavior in pigs has a postnatal component. These observations were unexpected, based on what is known from studies with other mammals.

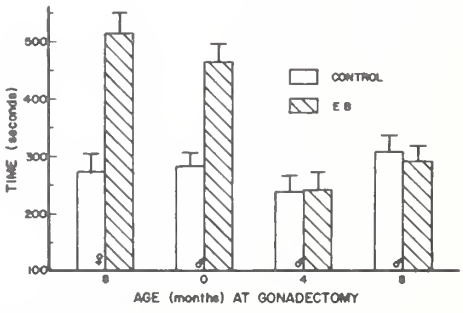


Figure 4—Time spent by barrows that were castrated at different ages and ovariectomized females in the end of the evaluation pen in which a mature boar was housed. Pigs were treated with cottonseed oil (control) or estradiol benzoate.

Embryo Spacing and Survival

William F. Pope and Ralph R. Maurer[1]

Introduction

Computer simulation studies, which are programmed to incorporate the economic variables of importance to swine production, have demonstrated that increasing litter size will increase a producer's profit margin more than any other biological variable. The average number of piglets born farrowing in the United States has unfortunately remained constant at eight to nine piglets/litter. The average number of embryos present initially in the uterus, however, is 13 to 15. A large portion of embryos are, thus, lost during gestation. One of the primary causes of this embryonic loss is a lack of sufficient uterine space to accommodate growth and development of all the embryos.

Pigs attempt to get around this restriction of uterine space by moving their embryos such that each embryo has initially the same volume of uterus in which to grow. Consequently, investigations were undertaken to better our understanding of how embryos are moved and "spaced" in the uterus. It was also of interest to examine if loss of embryos is a random event if some embryos are better able to survive while others are destined to die.

Procedure

Involvement of uterine muscles during embryo movement. Two days after mating, embryos were transferred from one oviduct to the opposite oviduct in 24 gilts. Then 4, 7, and 10 days later their uteri were removed, and position of the embryos was determined. Using this procedure, we observed that embryos recovered 6 days after mating were positioned in one uterine horn, still by the oviducts, and had not moved. Nine days after mating, recovered embryos had just begun to move and, by 12 days after mating, they were found throughout most of the uterus.

Small pieces of the uterine muscle were then removed and kept alive in the laboratory with an oxygenated Krebs-Ringer-Bicarbonate solution. These muscle strips were removed from an area of the uterus containing embryos or from the other side of the uterus that did not contain embryos. Using this procedure, the activity of uterine muscle exposed to embryos could be compared, within an animal, to the activity of muscle not influenced by embryos. By combining the frequency of muscle contractions with the strength of each contraction, expressed as Montevideo units, we observed that the activity of the muscle removed next to embryos (Fig. 1, labelled P or the solid line) increased at the same time as the embryos moved through the uterus. This increase in activity was observed whether the muscle strips pulled against 1 or 5 g of tension. The muscle strips removed from the uterus not exposed to embryos (labelled NP or the broken line) failed to increase in activity until day 12, a time when the embryos were moving throughout the uterus. Furthermore, by using various drugs, we determined that the stimulating influence of the embryo on the uterine muscle was not through the nervous system but rather through a hormone found in the fluids of the uterus.

Hormonal control of embryo movement. Ten gilts were used in an experiment to determine if estrogen, a hormone made by the embryo at the time of movement, was involved in moving the embryos through the uterus. Small beads were made with Silastic glue and estrogen such that they released estrogen in amounts similar to that released by the embryos. Ten of these beads were placed into the uterus of 5 nonpregnant gilts to determine if the beads could move through the uterus by releasing estrogen just as embryos do. Five control gilts received beads that released cholesterol instead of estrogen.

Five days later the position of the beads was examined. Those beads that released estrogen moved in the uterus, whereas, those that did not release estrogen remained at the site of injection (Fig. 2).

Do some embryos have a preferential chance for survival? Embryos recovered from naturally mated sows are not uniform in size and development. Even though these embryos come from the same sow, some will be larger and more developed than others. The question asked by this experiment was: Are embryos that are more developed better able to survive? To test this, pregnancy was established in gilts by transferring embryos differing in age by 2 days to the same recipient gilt. Specifically, embryos recovered from gilts 5 to 7 days after mating were transferred to the same nonpregnant gilt. These recipient gilts were then slaughtered 11 and 60 days into their pregnancies.

Results of this experiment (Table 1) indicated no difference in the ability of embryos transferred at age days 5 and 7 to survive to day 11. By mid-pregnancy (day 60), however, more fetuses that developed from embryos transferred at age day 7 survived than fetuses that developed from embryos transferred at age day 5. More embryos transferred at age day 5 survived to day 60 in the absence of than in the presence (42 vs 8 pct) of embryos transferred at age day 7. These observations suggest that each population of transferred embryos can survive alone but, when forced to cohabit in the uterus, fewer younger embryos survived to mid-pregnancy.

Results

Attempts to increase litter size are restricted to the capacity of the uterus to support more than eight or nine fetuses. Therefore, before substantial progress can be made in increasing litter size, it is important to understand this limitation in the capacity of the uterus. Research shows that pig embryos are distributed throughout the uterus such that each embryo has essentially the same volume of uterus in which to grow. The mechanisms by which the embryos move through the uterus and are distributed is, unfortunately, poorly understood.

From these experiments we find that the presence of the embryo stimulates contractions of the muscle in the uterus. One can postulate that these contractions act to move the embryo through the uterus in a manner similar to the movement of food through the gut. Furthermore, the embryo induces its own movement by producing a hormone in which estrogen is involved.

We also concluded from this research that of the eight to nine fetuses that survived and went on to become piglets, they were once slightly more developed as embryos. In other words, embryos that are more developed have a competitive advantage over less developed embryos. Swine producers have known for a long time that larger piglets do better than smaller littermates. We can now postulate, however, that a similar type of competitive advantage goes all the way back to the embryo. Using this observation to our advantage, we know that before we can increase litter size we must help the less developed embryos survive. This hopefully can be accomplished through further investigations.

[1]Pope was a predoctoral research physiologist in the Reproduction Unit at MARC. He is now at the Department of Animal Science, Cornell University, Ithaca, N.Y.; Maurer is a research physiologist, Reproduction Unit, MARC.

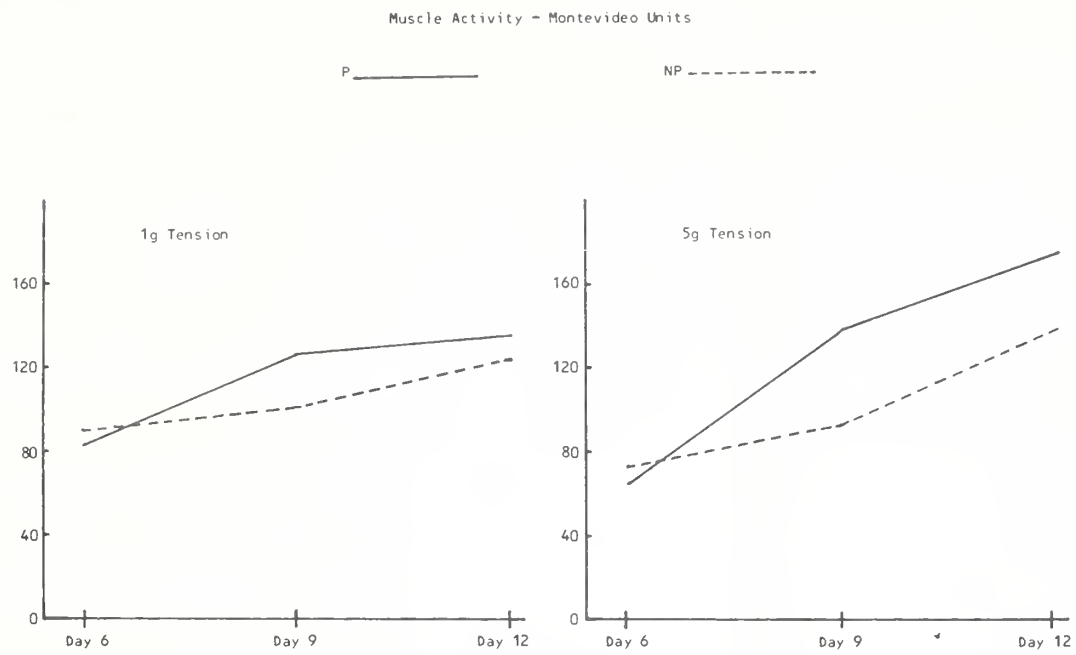


Figure 1—Activity (Montevideo units) of uterine muscle strips removed from day 6, 9, or 12 pregnant gilts at 1 and 5 g tension. Each point represents the mean of 8 gilts.

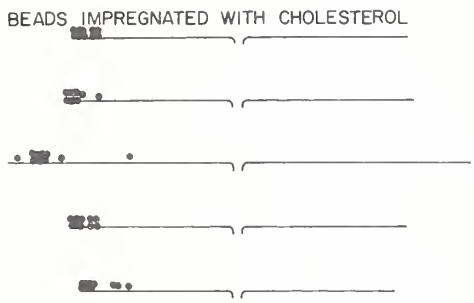


Table 1.—Percentage survival of day-5 and -7 embryos to day 11-and -60 of gestation

Recovery day	No. recipients utilized	No. recipients pregnant	Day-5 embryo: No. embryos transferred	Day-5 embryo: No. survived	Day-5 embryo: Percentage survival per recipient	Day-7 embryo: No. embryos transferred	Day-7 embryo: No. survived	Day-7 embryo: Percentage survival per recipient
11--------	10	[1]8	45	19	[4]42.3 ± 10.4	42	18	[4]43.1 ± 12.4
60--------	16	[2]8	87	6	[5]8.2 ± 6.9	83	53	[6]62.6 ± 7.7
60--------	10	[3]5	88	35	41.7 ± 9.9			

[1]Two recipients were not included as 5 of the 10 transferred day-7 embryos were recovered and none of the 11 day-5 embryos.
[2]Eight recipients were not included after failing to maintain pregnancy following the introduction of a total of 78 day-5 and 63 day-7 embryos.
[3]Five recipients were not included after failing to maintain pregnancy following the introduction of a total of 89 day-5 embryos.
[4 5 6]Means with different superscripts within rows are different ($P<0.01$).

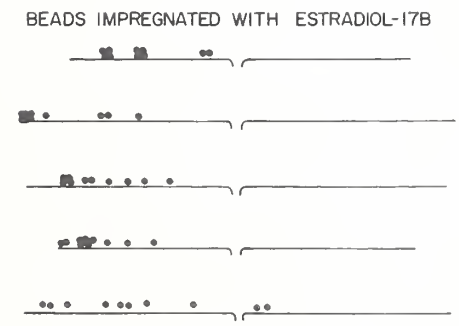


Figure 2—Distribution of Silastic beads (10/uterine horn) impregnated with cholesterol or estradiol-17β after 5 days in the uterus. Uteri were drawn to scale with body of the uterus aligned at the center. For illustrative purposes, the left horn contains the beads.

Blood Flow and Recognition of Pregnancy

Stephen P. Ford, Ronald K. Christenson, and J. Joe Ford[1]

Introduction

The period of behavioral estrus in the sow is from 48 to 72 h, and the estrous cycle occurs every 21 days (range 18 to 24 days). Ovulation normally occurs in the latter phase of behavioral estrus, about 35 to 40 h after the beginning of estrus. At ovulation, eggs are expelled from follicles (fluid-filled, blister-like structures on the surface of the ovaries), and from there the eggs enter the oviducts where union with the sperm and conception occur. Each ovulated follicle is then transformed into a structure called a *corpus luteum* (CL). The CL produces the hormone progesterone, which prepares for and maintains pregnancy. If fertilization does not occur, CL begin to degenerate about 13 days after mating, and progesterone secretion declines. This reduction in progesterone resulting from CL degeneration allows a new crop of follicles to grow and ovulate at the succeeding estrus, which occurs 21 days after mating. If the sow conceives at mating, however, CL are maintained and secretion of progesterone continues for the duration of pregnancy, which is approximately 113 days. If CL, and thus progesterone, are removed from the ovaries at any time during gestation, sows will abort. It is thus apparent that the embryos must, in some manner, prevent CL death if they are to survive.

We know that about a third of the embryos are lost during the first 25 days of gestation in swine. Fertilization rates are 95 percent; thus, most of the losses result from early embryonic death. If we are to obtain the "optimal" litter size from sows, thorough understanding of factors that potentiate embryo survival must be obtained. The following studies were conducted to gain insight into the mechanism(s) whereby the porcine embryos maintain luteal function and thus ensure a continuous supply of progesterone.

Procedure

Embryo induced increases in uterine blood flow. Uterine blood flow was monitored throughout an estrous cycle and the first 30 days of pregnancy in conscious sows using an electromagnetic blood flow transducer that was surgically implanted around the main uterine artery supplying each uterine horn and then exteriorized in the flank. Sows could then be literally plugged into a meter each day to obtain uterine blood flow (UBF) in ml/min. On days 12 and 13 of pregnancy, UBF increased threefold to fourfold (Fig. 1). No corresponding increase in UBF was observed on the same days during the previous estrous cycle (Fig. 2). In a separate study, when embryos were confined to one uterine horn, UBF increased only to the gravid horn on days 12 and 13 postmating. In addition, the CL on the ovary adjacent to the gravid horn of each sow contained more progesterone than CL from the opposite ovary. These data clearly suggest local stimulation of UBF and progesterone secretion by the early porcine embryos.

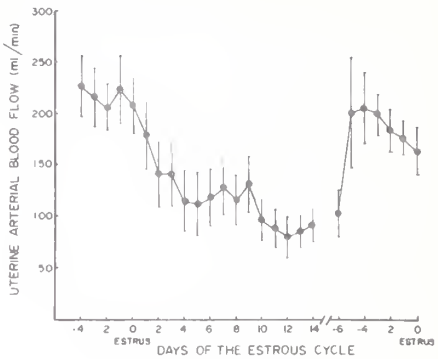


Figure 2—Pattern of blood flow through each uterine artery of 6 sows throughout the estrous cycle. Each point represents the mean ± SEM of 12 uterine arteries.

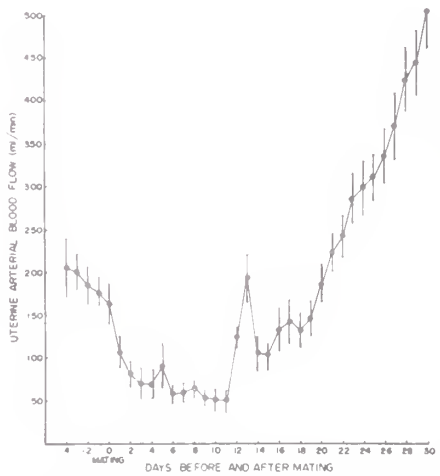


Figure 1—Pattern of blood flow through each uterine artery of 6 sows throughout the first 30 days of pregnancy. Each point represents the mean ± SEM of 12 uterine arteries.

Temporal association between increased UBF, estrogen, and pregnancy recognition. The time at which the embryo signaled its presence to the sow was determined by removing embryos from the uteri of sows on days 11, 13, and 15 of pregnancy. If embryos were flushed from uteri on day 11 of pregnancy, the CL degenerated at the normal time, and the sow returned to estrus on about day 21 (the expected day). If, however, embryos were flushed from uteri of sows on day 13 or 15 of pregnancy, the CL life-span and progesterone secretion were prolonged by approximately 4 days. Uterine blood flow was also obtained for each sow prior to embryo recovery as depicted in Table 1. As can be seen, marked increases in UBF were observed by day 13 of gestation. This is the first day during early pregnancy that CL life-span is prolonged when embryos are flushed from the uterus. This increased UBF may be a result of increased estrogen secretion by the embryos. The pig embryo develops the capacity to synthesize estrogens by day 12 of gestation, and increased concentrations of estrogens are observed in the uterine lumen and uterine venous blood of pregnant sows on days 11 to 15 of gestation (Table 2). Estrogens are known to exert a profound effect on uterine haemodynamics, with increases in blood flow to the uterus and ovaries resulting from estrogen administration. In a subsequent study, near physiological quantities of estrogen were injected into the lumen of the uterus of nonpregnant gilts between days 11 to 15 of the estrous cycle. These estrogen-treated gilts exhibited a prolonged luteal phase and delayed return to estrus. Consequently, estrogen has been proposed as the factor produced by the porcine embryo that maintains CL function during early gestation.

Increased CL blood flow during pregnancy recognition. One of the first events leading to the degeneration of the CL in the nonpregnant sow is a reduction in blood flow to the CL, which would limit their nutrient and oxygen supply and thus cause cell death. One way in which the embryos could rescue the CL during early pregnancy is by maintaining their blood supply. In a recent study, microspheres (25μ beads) with different radioactive

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Table 1.—Uterine arterial blood flows and estrous cycle lengths of nonpregnant and pregnant sows[1]

Day	Uterine arterial blood flow (ml/min)		Estrous cycle (days)	
	Nonpregnant	Pregnant	Nonpregnant	Pregnant
11--------	95.2 ± 17.3	86.6 ± 12.9	21.7 ± [1]0.9	22.0 ± 1.1
13--------	82.7 ± 13.3	[2]203.6 ± 22.9	21.0 ± .7	[2]25.8 ± .6
15--------	65.9 ± 12.6	128.8 ± 35.3	21.8 ± .6	[2]26.4 ± .9

[1]Values are mean ± SEM.
[2]Significantly different from nonpregnant value on same day ($P<0.05$).

Table 2.—Total amount of estradiol-17β and estrone in flushings from uterine horns of pregnant[1] and nonpregnant sows

Day after estrus or mating	Reproductive state	No. of uterine horns	Estradiol-17β (pg)	Estrone (pg)
11----------	Nonpregnant	10	[3]20 ± 3	[3]85 ± 21
	Pregnant			
	(Blastocysts 2-5 mm diam.)	8	[3]86 ± 58	[3]81 ± 18
	(Blastocysts 8–10 mm diam.)[2]	4	3418 ± 86	1132 ± 50
13----------	Nonpregnant	10	[3]54 ± 28	[3]60 ± 11
	Pregnant	12	[4]7204 ± 3753	[4]2029 ± 646
15----------	Nonpregnant	10	[3]51 ± 12	[3]131 ± 27
	Pregnant	10	[5]1327 ± 488	[5]819 ± 290

[1]Embryonic tissue was not removed from uterine flushings.
[2]Excluded from the analysis due to insufficient number of sows.
[3,4,5]Values are mean ± SEM; within each column, values with different superscripts are significantly different. $P<0.05$.

labels were used to estimate the flow of blood to uteri and ovaries of sows on days 9, 11, 13, and 15 of the estrous cycle and gestation. This technique is based on the premise that if a tracer is injected into the left ventricle of the heart, a good mixing of tracer and blood occurs, and the subsequent distribution of the tracer on its first passage through the systemic circulation reflects the distribution of cardiac output. Since microspheres are lodged in the capillary beds and do not affect subsequent blood flow or recirculate, they are a relatively permanent record of what blood flow was to any organ at the time of injection. These studies demonstrated that blood flow to the CL increased 60 percent on day 13 of gestation but not the estrous cycle (Fig. 3). To gain insight into the mechanism by which the conceptus stimulates increased CL blood flow during early pregnancy, ovaries were removed from gilts on day 13 of the estrous cycle, or pregnancy, and mounted in perfusion chambers. Ovarian periarterial sympathetic nerves were then subjected to electrical stimulation. These studies demonstrated that the activity of the sympathetic nerves of the ovarian vascular bed, which normally functions to restrict blood flow, was reduced by 80 percent on day 13 of gestation when compared to the activity of nerves in ovaries of nonpregnant gilts. Thus, a product of conceptus origin appears to reduce ovarian vascular contractility, resulting in the transient rise in luteal blood flow observed on day 13 of gestation.

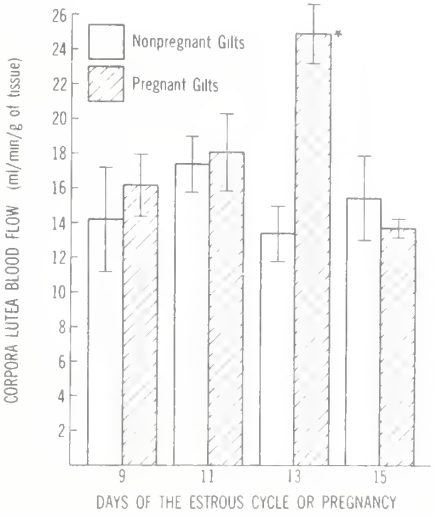

Figure 3—Average blood flow to corpora lutea of each ovary of pregnant (N = 8) and nonpregnant (N = 6) gilts on days 9, 11, 13, and 15. *On day 13, mean ± SEM differ ($P<0.01$).

Results

Pig embryos do not begin to attach to the wall of the uterus until after day 13 of gestation. Thus, we hypothesize that the embryos, while floating free in the uterine lumen, produce a vasodilatory substance that travels from the uterus to the ovary and ultimately maintains the function of the CL. On about day 13 in nonmated sows, the uterus produces a vasoconstrictor substance called prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$), which has been shown to travel via the blood stream to the ovary and kill the CL. It has been demonstrated that elevated levels of $PGF_{2\alpha}$ are found in blood draining the uterus at the time of CL death in this species. Concentration of $PGF_{2\alpha}$ in uterine venous blood of pregnant sows is lower on days 13 to 17 postmating when compared with nonpregnant sows on similar days postestrus. Thus, it is possible that increased blood flow to uterine horns containing embryos on days 12 and 13 of pregnancy may reduce $PGF_{2\alpha}$ concentrations in uterine venous blood by simple dilution, thus preventing death of the CL.

Alternatively, an embryonic factor that reduces the function of the ovarian periarterial sympathetic vasoconstrictor nerves or the sensitivity of the vascular smooth muscle to these nerves would prevent the vasoconstrictor effects of $PGF_{2\alpha}$ on the luteal vascular bed. During normal, as well as $PGF_{2\alpha}$-induced luteal regression, decreased progesterone secretion is associated with decreased blood flow through the CL. Prostaglandin $F_{2\alpha}$ has been implicated in the regulation of periarterial sympathetic neurotransmission and may decrease blood flow to CL by increasing the synthesis and (or) release of the neurotransmitter norepinephrine from blood vessels.

Relationship of Fetal Serum Albumin to Fetal Weight in Swine

Roger T. Stone[1]

Introduction

Currently, little can be said about a fetus that fails to grow at a normal rate except, compared to its littermates, that it has a smaller placenta with a correspondingly smaller blood flow and, most importantly, that it is less likely to survive after birth. To study impaired fetal and neonatal growth and survival, we must identify parameters that are more specific than weight and length. For this reason, we have studied serum proteins synthesized by the fetal pig liver in an attempt to identify proteins that are associated with fetal growth. We feel that once such quantifiable parameters are identified, they can be used as tools to study such questions as when do fetal growth rates begin to diverge within a litter and what factors may be responsible. Thus far, the only protein we have identified as being related to fetal growth is albumin.

Procedure

The effect of uterine crowding on fetal serum proteins was investigated in unilaterally ovariectomized-hysterectomized gilts. Surgery was performed 10 to 13 days prior to mating, the time required for the remaining ovary to compensate. Fetuses were collected from treated and control gilts at day 60 of gestation.

Results

The data in Figure 1 show the relationship of fetal weight to serum albumin concentration when values for both parameters are standardized so that the averages are zero for each litter. We found at both 50 to 60 days (top panel) and 75 to 85 days of gestation (lower panel) that smaller fetuses have lower albumin concentrations than heavier fetuses. We obtained similar results at other states of gestation. The data summarized in Table 1 show that uterine crowding also affected the albumin concentration in fetal serum. Based on the number of fetuses per uterine horn, these fetuses were not crowded at the time these samples were collected. Since the number of ovulations on the remaining ovary was equal to that in the control group, however, we can assume they were crowded earlier in development. This is consistent with previous findings that most fetal losses occur prior to day 30 of gestation in the pig. Perhaps important to future studies is that early uterine crowding affected albumin without affecting fetal weight.

From these results, we feel that the synthesis of serum albumin by the fetal liver can provide a biochemical trait that can be studied in relation to fetal growth and survival. More rapid progress in understanding factors regulating fetal growth should be possible by studying the product of a single gene that is related to growth than by studying the overall effect of a multitude of unidentified genes that contribute to growth.

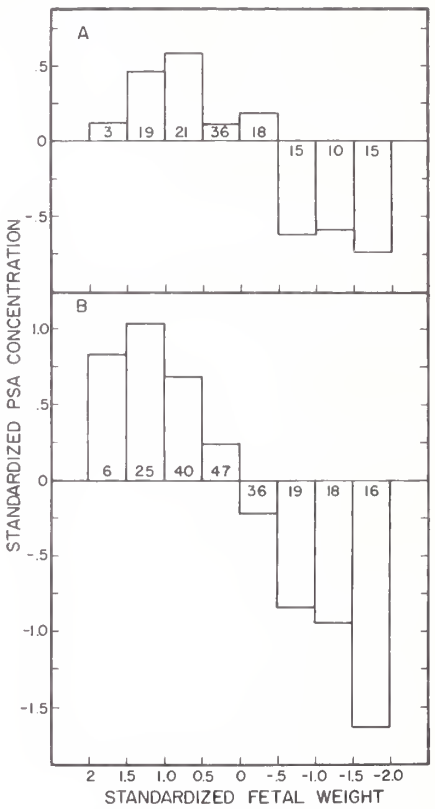

Figure 1—The relationship of fetal weight to fetal serum albumin. Enclosed in the bars are the number of fetuses in each group.

Table 1.—The effect of uterine crowding on fetal weight and serum albumin

Group	No. of litter	Fetuses per uterine horn	Fetal wt	Albumin
			(gm/fetus)	(ug/ml)
Control ----------	8	5.1 ± .4	115.3 ± 1.7	[1]653 ± 41
Crowded --------	9	6.4 ± .6	111.0 ± 2.1	[1]342 ± 50

[1](P>0.01).

[1]Stone is a research physiologist, Reproduction Unit, MARC.

Effect of Energy Intake during Late Gestation on the Fetus and Newborn Pigs

Jong-Tseng Yen, Wilson G. Pond, Ronald D. Eichner, Ralph R. Maurer, and Ronald K. Christenson[1]

Introduction

Although crushing by the sow, starvation, and weakness have been considered the primary causes of baby pig death, poor thermoinsulation and inadequate thermostability of newborn pigs are major predisposing factors. Newborn pigs almost totally rely on glycogen and other carbohydrate energy sources for maintaining body temperature. An increase in body glycogen stores at birth may improve the chance of survival of the newborn. Well documented research shows that liver and muscle glycogen stores in fetal pigs increase dramatically in the last 3 to 4 weeks of gestation. Thus, the most logical time for dietary manipulation of fetal glycogen stores in swine appears to be the very last stage of gestation. In laboratory rats, fasting and refeeding a fat-free diet produced a dramatic increase in tissue glycogen content. Thus, one experiment was conducted to determine the effect of fasting and refeeding a fat-free diet during late gestation upon glycogen stores in fetal pigs. A second experiment was conducted to determine the effect of doubling the daily energy intake of sows from day 100 of gestation until farrowing on pig weight, survival, and weaning weight at 28 days of age.

Procedure

Experiment 1. Nineteen Swedish Landrace sows mated to Swedish Landrace boars were randomly assigned, on day 91 of gestation, to three groups: (1) control—fed standard 13-percent protein corn-soybean meal gestation diet at 4 lb/day to day 112 of gestation; (2) 4-day fast—fed the standard diet to day 94 of gestation, then fasted from day 95 to 98 and refed a fat-free diet *ad libitum* from day 99 to 112 of gestation; and (3) 8-day fast—treated the same as group 2, except that the fast began on day 91 and extended through 98 of gestation. The fat-free diet contained 66.1 percent dextrose, 30.0 percent solvent-extracted soybean meal, 2.4 percent dicalcium phosphate, 0.5 percent limestone, 0.4 percent iodized salt, 0.4 percent trace mineral premix, and 0.2 percent vitamin premix. All fetuses were removed from sows by Caesarean section on day 112 of gestation to determine tissue glycogen contents.

Experiment 2. Eighty-eight sows from eight breed groups were fed daily 4 lb of a standard 14-percent protein corn-soybean meal diet through day 100 of gestation (6,000 Kcal digestible energy/day). From day 100 of gestation to farrowing, each sow received either the basal diet (6,000 Kcal digestible energy/day) or the basal diet plus 4 lb cornstarch (12,000 Kcal digestible energy/day). Total number of live and stillborn pigs and individual pig birth weights were recorded within 12 h after birth; individual body weights of survivors were recorded on day 28. All sows were fed a 16-percent protein corn-soybean meal diet *ad libitum* from day 1 to day 28 of lactation.

Results

Experiment 1. Effects of fasting and refeeding on daily intake during the refeeding period on maternal and fetal tissue glycogen concentrations and on fetal body and liver weights are summarized in Table 1. Sows fasted for 4 or 8 days and refed *ad libitum* the fat-free diet had a significantly greater average daily feed intake during the refeeding period than did control sows. No differences, however, were observed among treatment groups in maternal and fetal tissue glycogen concentrations, in number of fetuses per sow, or in fetal body and liver weights. These results indicate that fasting followed by the refeeding of a fat-free diet to pregnant sows during late gestation does not increase maternal or fetal tissue glycogen content and, therefore, appears to be of no value in improving pig survival in early postnatal life.

Experiment 2. Effects of gestation energy level from day 100 of gestation to farrowing on pigs and sows are summarized in Table 2. Maternal energy intake during late gestation had no effect on pig birth weight, number of pigs per litter at birth, 28-day pig weight, or survival rate. Body weight at farrowing of sows fed 12,000 Kcal digestible energy daily from day 100 of gestation to farrowing was not significantly greater than that of sows fed 6,000 Kcal/day. Feed consumption during lactation was similar for the two diet groups. The lack of a positive response to energy supplementation of the maternal diet during late gestation, as observed in the present experiment, agrees with previous reports and suggests that, in the normal pregnant sow, transfer of glucose across the placenta is refractory to elevated blood glucose concentration or that the homeostatic control of blood glucose by the pregnant sow is sufficient in chronic carbohydrate leading to maintain blood glucose below the threshold for increased placental transfer.

[1]Yen is a reseach animal scientist, Pond is the research leader, and Eichner was a research chemist, Nutrition Unit; Maurer and Christenson are research physiologists, Reproduction Unit, MARC.

Table 1.—Effects of fasting and refeeding on daily intake, tissue glycogen concentrations, and fetal body and liver weight

Item	Treatment (1) Control	(2) 4-day fast	(3) 8-day fast
No. of sows	6	7	6
Sow daily feed, lb[1]	4.00	5.63	5.02
Sow adipose tissue glycogen, mg/g[2]	.22	.20	.26
Sow uterus glycogen, mg/g[2]	2.96	2.80	3.12
No. of fetuses/sow[2]	7.83	7.14	9.50
Fetal body weight, lb[2]	2.88	3.06	2.52
Fetal liver weight, g[2]	46.35	37.61	34.88
Fetal liver glycogen, mg/g[2]	89.17	85.71	85.83
Fetal muscle glycogen, mg/g[2]	60.00	62.57	61.67

[1]Treatment 1 value differs ($P<0.01$) from treatment 2 and 3 values.
[2]No treatment effect ($P>0.05$).

Table 2.—Effects of maternal energy level on reproductive performance of sows

Item	Dam energy intake, Kcal/day 6,000	12,000
No. of litters	44	44
Avg. birth weight, lb[1]	2.99	3.08
No. of pigs/litter at birth[1]	9.3	9.5
28-day pig weight, lb[1]	12.94	12.85
No. of pigs/litter at 28 days[1]	7.2	6.7
Survival[1], percent	77.7	71.1
Sow weight at farrowing, lb[1]	361.5	371.1
Sow weight at 4-week lactation, lb[1]	356.4	362.8
Feed consumed during 4-week lactation, lb[1]	222.0	218.5

[1]No significant treatment effect.

Calcium Chloride as a Regulator of Feed Intake and Weight Gain in Pigs

Jong-Tseng Yen, Wilson G. Pond, and Ronald L. Prior[1]

Introduction

Research shows that feed restriction improves the lean-to-fat ratio of growing-finishing pigs. In gestating swine, excessive feed consumption increases feed costs, produces obesity, and impairs reproductive performance. Daily hand feeding controls feed intake and weight gain in pigs but drastically increases labor cost. In recent years, studies show that the addition of calcium chloride to the diet restricted feed intake and controlled weight gain of self-fed pigs. The mechanism whereby the mineral salt regulates the pig's appetite is not clear. Previously, an increase in blood chloride concentration was detected in pigs fed mineral salt. An elevated blood chloride concentration will reduce the reabsorption of bicarbonate ions from the renal tabules and precipitate acidosis; however, we did not know whether acidosis occurred in the pigs fed the mineral salt. If it did, then the addition of a buffer such as sodium bicarbonate should correct the acidosis and remove the depressive effect of calcium chloride on the feed intake and weight gain of pigs. To test this hypothesis, we conducted a study.

Procedure

Twenty-one Yorkshire X Swedish Landrace crossbred barrows averaging 137 lb were allotted on the basis of ancestry and weight to three dietary treatments. The composition of the three diets is shown in Table 1. Diet 1, the basal diet, was a 14-percent crude protein, fortified, corn-soybean meal diet. Diet 2 was a modification of diet 1, with 4-percent calcium chloride dihydrate and 2.22-percent sodium triphosphate added at the expense of corn. Diet 3 was the same as diet 2 except that 2.03-percent sodium bicarbonate was added at the expense of corn. All pigs were self-fed and housed individually for 42 days in an environmentally regulated finishing barn equipped with a solid concrete floor and flushing gutter at the rear of the pen. Water was provided continuously by automatic nipple waterer. Feed consumption was recorded biweekly. Pig weights and blood samples were taken at the outset and then biweekly. Blood samples were analyzed for blood pH, concentrations of carbon dioxide, oxygen, and hemoglobin, and for plasma concentrations of chloride, calcium, phosphorus, sodium, and potassium. Blood concentrations of bicarbonate ions, total carbon dioxide, and base excess were calculated.

Results

Average daily feed intake, average daily gain, and gain/feed were significantly lower for pigs fed Diet 2 (with 4-pct calcium chloride) than for those fed Diet 1 (the basal diet) (Table 2). Diet 2 produced a significant increase in plasma chloride concentration; however, plasma concentration of sodium was similar for pigs fed Diet 2 and those fed Diet 1. When pigs were fed Diet 3 (with 4-pct calcium chloride and 2.03-pct sodium bicarbonate), feed intake and feed efficiency were similar to those of pigs fed Diet 1. Daily gain of pigs fed Diet 3 was significantly higher than that of pigs fed Diet 2 but significantly lower than that of pigs fed Diet 1. Plasma chloride level of pigs fed Diet 3 was significantly lower than that of pigs fed Diet 2 but significantly higher than that of pigs fed the basal diet. Plasma concentration of sodium of pigs fed Diet 3 was similar to that of pigs fed either the Diet 2 or Diet 1.

Pigs fed Diet 2 had significantly lower blood pH, bicarbonate, total carbon dioxide, and base excess than those fed either the basal or Diet 3. Both blood concentrations of carbon dioxide and oxygen were similar for pigs fed the three diets. The ratio of plasma sodium to chloride in pigs fed either Diet 2 or Diet 3 was significantly lower than that in pigs fed Diet 1. Diet 2 resulted in a significantly higher blood chloride-to-bicarbonate ratio than did Diet 1 or Diet 3.

This study substantiates our previous observations that calcium chloride decreases feed intake and reduces weight gain in pigs. It also provides clear evidence that metabolic acidosis is the mode of action whereby calcium chloride suppresses appetite and weight gain. This acidosis is caused by the increased plasma chloride level resulting from calcium chloride ingestion. After being ingested, the chloride portion of calcium chloride is absorbed while the calcium portion is excreted in the feces as calcium phosphate. The data suggest that elevated plasma chloride sets off a sequence of events that leads to a reduction in the body's bicarbonate ion concentration and a shift of the pH of body fluid toward acidosis, which causes a suppressed appetite.

The response of pigs fed the diet containing both calcium chloride and sodium bicarbonate provides further support for the contention that acidosis, caused by a bicarbonate ion deficiency, is responsible for the effect of calcium chloride on pigs. When an exogenous source of bicarbonate ion was supplied for the pig in the form of sodium bicarbonate, the appetite-suppressing effect of calcium chloride was eliminated. The blood pH and blood concentrations of bicarbonate ion, total carbon dioxide, and base excess were also restored. Despite the persistent high plasma chloride level, and thus low plasma sodium-to-chloride ratio, the chloride-to-bicarbonate ratio in pigs fed Diet 3 was restored to that observed in pigs fed the basal diet.

[1]Yen is a research animal scientist, Pond is the research leader, and Prior was a research chemist, Nutrition Unit, MARC.

Table 1.—Composition of test diets

Ingredient	Diet (1) Basal	(2) $CaCl_2$	(3) $CaCl_2$ + $NaHCO_3$
	(pct)		
Corn, No. 2 yellow	81.90	75.68	73.65
Soybean meal	14.00	14.00	14.00
Dicalcium phosphate	2.40	2.40	2.40
Limestone	.50	.50	.50
Iodized salt	.40	.40	.40
Trace mineral premix	.40	.40	.40
Vitamin premix	.40	.40	.40
Calcium chloride dihydrate	----	4.00	4.00
Sodium triphosphate	----	2.22	2.22
Sodium bicarbonate	----	----	2.03
Total	100.00	100.00	100.00

Table 2.—Effects of dietary treatment on performance and on plasma and blood parameters of pigs after 42 days on test[1]

Item	Diet (1) Basal	(2) $CaCl_2$	(3) $CaCl_2$ + $NaHCO_3$
Avg. daily feed—lb	[2]7.19 ± 0.24	[3]4.93 ± 0.20	[2]6.78 ± 0.29
Avg. daily gain—lb	[2]1.89 ± .04	[3]1.06 ± .11	[4]1.58 ± .04
Gain/feed	[2].26 ± .01	[3].21 ± .02	[2 3].23 ± .01
Plasma Cl, mmoles/liter	[2]99.0 ± 2.0	[3]112.0 ± 1.0	[4]107.0 ± 2.0
Plasma Na mmoles/liter	143.0 ± 8.0	133.0 ± 9.0	126.0 ± 7.0
Blood pH	[2]7.32 ± .02	[3]7.21 ± .02	[2]7.34 ± .01
Blood P CO_2, mm Hg	59.0 ± 4.0	59.0 ± 8.0	65.0 ± 4.0
Blood PO_2, mm Hg	27.0 ± 5.0	29.0 ± 4.0	26.0 ± 3.0
Blood HCO_3^-, mmoles/liter	[2]30.0 ± 2.0	[3]22.0 ± 1.0	[2]34.0 ± 2.0
Blood total CO_2, mmoles/liter	[2]32.0 ± 2.0	[3]24.0 ± 1.0	[2]36.0 ± 3.0
Blood base excess, mmoles/liter	[2]5.2 ± 2.0	[3]4.3 ± 1.0	[2]8.1 ± 3.0
Na^+/Cl^-	[2]1.44 ± .07	[3]1.19 ± .03	[3]1.18 ± .04
Cl^-/HCO_3^-	[2]3.3 ± .2	[3]5.0 ± .4	[2]3.1 ± .4

[1]Values are means ± standard error of the mean for 7 barrows weighing 137 lb initially
[2 3 4]Values in the same row with different superscripts differ ($P<0.05$).

Serum Transferrin and Albumin in Protein-Deficient Young Pigs

Jong-Tseng Yen, Wilson G. Pond, and Roger T. Stone[1]

Introduction

One of the clinical signs of protein malnutrition in young animals is depressed serum albumin and whole blood hemoglobin. Recent evidence suggests that serum transferrin concentration is also a sensitive index of protein deficiency in young pigs. Studies in children indicate that plasma transferrin, plasma albumin, plasma iron, and blood hemoglobin are reduced in protein-energy malnourished (PEM) children and suggest that plasma transferrin is more sensitive than other blood constituents in diagnosing PEM. They also conclude that iron deficiency may be partially responsible for the low blood hemoglobin and plasma transferrin values in the PEM children. Because many similarities exist between pigs and humans in biochemical and anatomical changes associated with protein deficiency, tests should be made to assess the relative effects of dietary iron and protein level on serum transferrin and to establish whether serum transferrin or serum albumin is a more valid index of protein status in young pigs.

Procedure

Seventy-two crossbred (Swedish Landrace X Chester White) 4-week old barrows with 14.3-lb average initial weight were used in a factorial arrangement with two levels of dietary protein (10 and 18 pct) and three levels of dietary iron (400, 600, and 800 ppm). The two levels of dietary protein were achieved by varying the amount of dried skim milk and cornstarch in the diets. Ferrous sulphate was used as supplemental iron source. Each of the six diets was fed to three pens of four pigs each for 42 days. The pigs were housed in an environmentally regulated nursery and self-fed. Water was provided at all times by nipple waterer. Body weight gains and feed consumption of pigs were determined biweekly. Blood samples were taken from each pig on days 0, 14, 28, and 42 of test and analyzed for hemoglobin, hematocrit, serum total protein, serum albumin, serum transferrin, serum iron, and total iron-binding capacity.

Results

Average daily body weight gain, gain/feed, hemoglobin, and serum concentrations of albumin, transferrin, and iron are summarized in Table 1. After 28 days on test, young pigs fed low protein diets had daily weight gains significantly lower than those fed high protein diets. Within each protein level, dietary iron level did not affect the weight gain of pigs. The gain-to-feed ratio was significantly lower for pigs fed low protein diets than for those fed high protein diets after pigs had been on test for only 14 days. Dietary iron level showed no effect on gain/feed. No interaction was observed between dietary protein and iron level on weight gain or gain/feed. Concentrations of hemoglobin and serum albumin in pigs were similar among all pigs on day 14 of the test but were significantly more reduced in pigs fed low protein diets than in those fed high protein diets on days 28 and 42. Significantly lower serum concentrations of transferrin and iron were detected in pigs fed low protein diets as compared with those fed high protein diets after pigs had been on test for only 14 days. Dietary iron level did not show any effect on the measured blood parameters.

The present study confirms that protein deficiency produces a reduction in weight gain, feed efficiency, blood hemoglobin, and serum concentrations of albumin, transferrin, and iron. It further demonstrates that inadequacy of dietary protein rather than dietary iron is responsible for the depression of serum iron in protein malnourished young pigs. In agreement with studies with PEM children, the results of the present study indicate that serum transferrin concentration is more sensitive than serum albumin for early detection of protein malnutrition in young pigs.

Table1.—Effect of dietary protein and iron levels on performance and blood constituents in young pigs[1]

	Diet					
	1	2	3	4	5	6
Item: Protein level, percent: / Iron level, ppm:	10 / 400	18 / 400	10 / 600	18 / 600	10 / 800	18 / 800
Daily gain, lb:						
14-day	0.26	0.38	0.26	0.46	0.19	0.37
28-day[2]	.46	.64	.41	.64	.41	.61
42-day[2]	.61	.83	.52	.79	.56	.78
Gain/feed, lb:						
14-day[2]	.38	.59	.39	.64	.23	.75
28-day[2]	.43	.64	.41	.65	.38	.64
42-day[2]	.42	.56	.38	.55	.36	.57
Hemoglobin, g/dl:						
14-day	10.3	10.6	10.4	10.1	10.7	10.0
28-day[2]	10.2	10.6	9.9	11.0	10.0	10.9
42-day[2]	9.9	10.9	10.0	11.3	10.1	11.5
Serum albumin, g/dl:						
14-day	2.2	2.2	2.1	2.1	2.1	2.3
28-day[2]	2.3	2.8	2.2	3.2	2.3	2.9
42-day[2]	2.3	3.0	2.2	3.3	2.3	3.4
Serum transferrin, mg/ml:						
14-day[2]	1.4	1.7	1.4	2.0	1.4	1.7
28-day[2]	1.7	2.5	1.5	2.4	1.6	2.3
42-day[2 3]	2.1	2.5	1.9	2.8	1.9	2.9
Serum iron, µg/dl:						
14-day[2]	167.0	187.0	171.0	183.0	157.0	190.0
28-day[2]	152.0	165.0	167.0	213.0	159.0	203.0
42-day[2]	161.0	197.0	142.0	160.0	149.0	166.0

[1]Values are means for 3 replicates of 4 pigs weighing 14.3 lb initially.
[2]Significant protein effect ($P<0.05$).
[3]Significant interaction between protein and iron levels ($P<0.05$).

[1]Yen is a research animal scientist and Pond is the research leader, Nutrition Unit; and Stone is a research physiologist, Reproduction Unit, MARC.

Factors Affecting Appetite and Feed Intake

Jerome C. Pekas, Wilson G. Pond, and Jong-Tseng Yen[1]

Introduction

Increasing food intake has been identified as one of the most important factors for improving the performance of meat animals. Food intake is regulated by complex physiological mechanisms. The mechanisms of regulation are poorly understood in spite of extensive research involving many species of animals, including the human, conducted by scientists with such varied professional backgrounds as psychology, physiology, nutrition, and biology. Emphasis in these scientific investigations has been on mechanisms for both suppression and stimulation of food intake.

The initial emphasis in meat animal research has been to stimulate food intake on the premise that the efficiency of feed utilization would not decrease as food intake was increased. It is important to acknowledge at the outset that this is an assumption that urgently needs to be tested. Unfortunately, the assumption has not been adequately tested to this date simply because methods have not been developed to stimulate food intake over sustained periods. Although drugs have been developed that stimulate feed intake, these have been effective only over periods of a few minutes to an hour but have little or no effect on feed intake over a sustained period. In meat animal production, feed intake must be maintained at an elevated level for a sufficient period of time to derive a production benefit. Obviously, experimental investigations into the effects of feed intake in excess of normal intake cannot be conducted until a reliable method is developed to induce excessive feed intake.

Three aspects of food intake regulation have been explored. One involved a surgical method for direct administration of a portion of normal feed intake. We hoped that in addition the animals would ingest a normal meal voluntarily from the feeders so that the sum of the quantities, voluntary ingestion plus that administered directly into the stomach, would be distinctly greater than normal feed intake. There is scanty evidence that the monkey and human, under these conditions, do overeat. The second approach was to simulate a small appetite by feed restriction and to observe the effect on animal performance. The third approach relates to a recent theory that has been gaining popularity—that the hormone cholecystokinin interacts directly with the brain to suppress or stop eating. Numerous samples of brain and gastrointestinal tissues from numerous pigs with a variety of nutritional backgrounds have been obtained at slaughter and submitted to other research institutes for analysis. The analyses of these samples are incomplete.

Procedure

Effect of direct gastric feeding on voluntary feed intake of young pigs. Ten crossbred castrated male pigs, selected from three litters on the basis of initial body weights, were assigned to two groups of five pigs each. The number of pigs was restricted by the facilities required. One pig was a nonsurgical control (C) and the other four were prepared surgically with a gastric fistula (GF). The GF pigs were administered either 0 percent (GF–0; surgical control), 20 percent (GF–20), 40 percent (GF–40), or 60 percent (GF–60) of the quantity of diet ingested voluntarily by the C animals. All pigs had access to an excess of food for 17 h daily. The experiment was initiated after recovery from surgery and training of the animals. The animals were 82 days of age when the experimental data collection was started. The GF provided a means to extrude a semiliquid meal directly into the stomach. The semiliquid meal was prepared by blending the diet with water to obtain 61.5-percent dry matter. The semipurified diet consisted of dried milk powder, cornstarch, solka floc, corn oil, and the necessary vitamins and mineral premixes to satisfy the nutrient requirements. The GF pigs were fed daily for 10 consecutive days at 2 p.m. after a 7-h fast immediately before an excess of dry diet was offered in the feeder. The feeders were removed 17 h later (7 a.m.). The C and GF–0 animals were offered an excess of the same food for 17 h daily (2 p.m. to 7 a.m.). Voluntary feed consumption was measured daily for all pigs by measuring the amount of feed remaining in the feeder and of any wastage. Although the GF–0 pigs did not receive the semiliquid diet through the fistula, they were handled, nevertheless, as the other GF pigs.

Effect of intermittent long-term gastric fistula feeding on voluntary food intake. A second experiment, using the same breed of animals and the same facilities, differed from the first in several important points. A conventional corn-soybean diet was finely ground to obtain a small particle size and mixed with 20 percent of the semipurified diet described for the first experiment. The mixture was blended with water to obtain 50-percent dry matter. The experiment was initiated when the animals were 104 days of age and continued until the pigs were an average of 162 days of age. During the 58-day study, the semiliquid diet was extruded into the stomach daily for 4 consecutive days and discontinued the next 3 consecutive days; this routine was repeated each 7-day period for eight periods. Two replicate groups of five pigs each were used. Both a C and a surgical control (GF–0) were used. Two pigs in each replicate group were administered 50 percent (GF–50) of the quantity of dry matter consumed by the C pig, and one pig was administered 100 percent (GF–100). All 10 animals were slaughtered and the carcasses dissected to measure the proportions of lean meat, fat, and bone. Measurements were recorded from the gastrointestinal organs. Samples of the gastrointestinal tract were removed for histological evaluations but will not be reported here because the evaluations are not complete.

Feed restriction and animal performance. We conducted an experiment to observe the effect of feed restriction on animal performance and carcass traits in pigs. The evidence would not be expected to reflect on physiological regulation of feed intake but rather to reflect what might be expected from animals with unusually small appetites. The study involved 7 Pietrain and 14 Spotted Poland China (Spot) gilts at 77.2-lb initial body weight. These animals were divided into seven replicate groups of one Pietrain and two Spot gilts each. The Pietrain and one Spot in each group were fed free choice; the second Spot was restricted to the feed intake of the Pietrain. The Pietrain served as a reference breed because it is muscular, has a reputation for producing carcasses of exceptionally high lean percentage and soft musculature, and has a small appetite when compared to other breeds of swine. The objective of this particular experiment was to determine if the lean percentage and quality of the Spot could be changed toward that of the Pietrain by restricting feed intake of the Spot to that of voluntary intake by the Pietrain. Data were collected on feed consumption, body weight gain, and various carcass, tissue, and blood characteristics.

[1]Pekas is a research physiologist, Pond is the research leader, and Yen is a research animal scientist, Nutrition Unit, MARC.

Results

Direct gastric feeding and the effect of voluntary feed consumption on young pigs. The data from the first study demonstrated clearly that these young pigs were not confused by the quantity of feed placed directly into the stomach. Voluntary feed intake was adjusted with surprising precision for the quantity of dry matter placed into the stomach so that the total quantity of dry matter (dry matter placed in the stomach plus dry matter consumed voluntarily) was virtually the same for the C and GF–0 pigs whether 20, 40, or 60 percent of control intake was administered through the fistula. The data demonstrated clearly that the surgical procedures did not have a detrimental effect on appetite or body weight gain. The rate and efficiency of body weight gain of the GF–20, GF–40, and GF–60 pigs were similar to those of the C and GF–0 control pigs (Table 1).

The feed consumption data from each of the GF animals, including the GF–0 animals, were computed in percent body weight for the 10-day GF feeding period and the 3-day preliminary period. The 3-day preliminary period was included in this analysis to allow each animal to express voluntary feed intake without feed administration through the fistula. The data were analyzed by correlation and regression methods, and the results are shown in Figure 1. The plot of the regression line shows clearly that as the quantity of feed administered through the GF was increased, voluntary intake decreased; the regression coefficient indicates that for each 1.0 lb of dry matter administered through the fistula, animals consumed 1.09 lb less feed voluntarily. This suggests that voluntary feed intake is suppressed 9 percent greater than the quantity administered directly into the stomach. It is premature to speculate on the biological significance of this 9 percent discrepancy. The correlation coefficient, r^2, indicates that 86 percent of the variation in voluntary feed intake can be predicted from the quantity administered through the GF by use of the regression equation and confirms that the regression equation is a good fit of the observed data.

We conclude from the results of this experiment that feed intake by the pig is regulated physiologically with good precision. The data indicate that gastric factors play a prominent role in the physiological regulation mechanisms; gastric factors involved might include distention of the muscular wall and the volume of the meal. The data indicate that such oral factors as taste, smell, chewing, and swallowing probably do not play a prominent role in the pig as suspected in other animals, including humans. The results show clearly that the pig cannot be confused by partial direct gastric feeding to consume sufficient quantities by voluntary ingestion to result in greater than normal quantities of total diet intake daily. We hoped that partial gastric feeding would provide an experimental model to obtain excessive dietary intake consistently to determine the benefits, if any, that could be expected if a strain of animals with greater than normal appetites could be developed genetically (or induced pharmacologically).

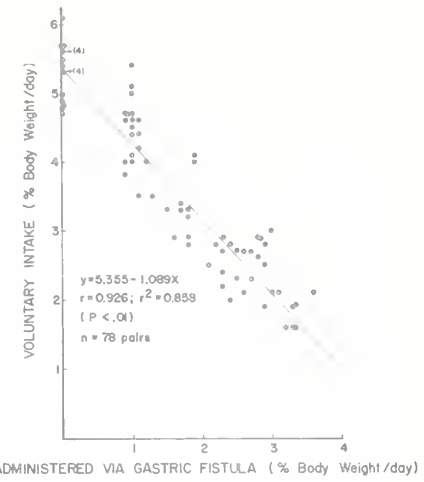

Figure 1—Plot of daily voluntary vs gastric administered feed intake data of the 6 GF–20, GF–40, and GF–60 pigs (78 data points) and the correlation and regression analyses of the data.

Effect of sustained gastric feeding to slaughter weight. The differences between treatments are of such a magnitude to support the conclusion that feed intake, rate and efficiency of gain, carcass composition, and gross anatomy of gastrointestinal and other organs were not affected by direct gastric administration of 50 or 100 percent of voluntary dry matter intake by the C animals. Total feed intake (sum of dry matter administered via the fistula plus voluntary intake) over the 58-day evaluation period was 301, 313, and 300 lb for the controls (C and GF–0), GF–50, and GF–100 groups, respectively.

As with the first experiment involving the young pigs, daily feed intake for each GF animal was computed as percent of body weight/day over the entire 58-day evaluation period, and the data were analyzed by correlation and regression methods. In this experiment, the GF–0 pigs were not included in the analysis because each of the GF–50 and GF–100 animals did not receive dietary dry matter through the fistula for 3 days out of each 7-day period and thus contributed substantial data points to indicate voluntary intake at 0 GF administration. In this experiment, r^2 was 0.673; thus, the regression equation accounted for 67 percent of the variation in voluntary feed intake. The regression equation was voluntary intake (percent of body weight/day) = 3.392 – 0.684 GF administered (percent of body weight/day). The regression coefficient, – 0.684, indicates that voluntary feed intake was suppressed 0.684 lb for each 1.0 lb of dry matter administered directly into the stomach. This regression equation is considerably different than that obtained

Table 1.—Summary of overall (15 day) body weight gain, feed intake, and gain efficiency

Parameter	Treatment[1] C	GF (0 pct)	GF (20 pct)	GF (40 pct)	GF (60 pct)
Initial body wt (lb):					
Replicate 1	46.3	45.2	52.9	47.4	46.3
Replicate 2	40.8	41.9	41.9	45.2	46.3
Avg.	43.5	43.5	47.4	46.3	46.3
Gain (lb) (15 day):					
Replicate 1	28.7	24.3	30.9	22.0	28.7
Replicate 2	30.9	45.2	35.3	45.2	39.7
Avg.	29.8	34.7	33.1	33.6	34.2
Total feed (lb) (16 day):					
Replicate 1	51.2	54.3	61.3	45.6	50.3
Replicate 2	66.4	66.1	56.1	62.2	64.0
Avg.	58.8	60.2	58.7	53.9	57.2
Gain efficiency (lb gain/lb feed):					
Replicate 1	.560	.446	.503	.483	.570
Replicate 2	.465	.684	.629	.726	.620
Avg.	0.513	0.565	0.566	0.605	0.595

[1]C denotes control; GF denotes gastric fistula.

with the young pigs. The correlation coefficient indicates that the regression equation did not fit the raw data as nicely as in the experiment with the young pigs. Close inspection of the regression equation and the raw data in this experiment with the older pigs confirms that the experimental design involving 3 days of no GF feeding and 4 days of GF feeding in each 7-day period accounts for the discrepancy; the data show clearly that total dry matter intake (sum of dry matter administered via the fistula and that consumed voluntarily) was consistently lower during the 3 days of no fistula feeding than during the 4 days of fistula feeding. This trend was observed for both the GF–50 and GF–100 groups of animals but was more pronounced in the GF–100 group.

From these results we conclude that the surgery and GF were well tolerated by these animals and that administration of 50 or 100 percent of the dry matter ingested voluntarily by control pigs did perturb voluntary feed intake on a short-term basis (7-day period) but did not affect dry matter intake over the 58-day evaluation period. The fundamental findings of this latter experiment are in agreement with the first experiment with the younger pigs and indicate that feed intake by the pig is regulated with surprising accuracy by physiological mechanisms sensitive to gastric factors. Gastric feeding of substantial quantities intermittently for a sustained period did not induce the intake of dietary dry matter distinctly in excess of normal feed intake.

Effect of restricted feed intake. Feed intake of one group of Spot gilts was restricted to that of the Pietrain gilts (82 pct of the full-fed Spot gilts) and demonstrated that the level of feed intake did not explain the apparent differences between the Spot and Pietrain breeds. The 18-percent feed restriction stimulated glucose incorporation into lipid components and reduced backfat thickness but had no significant effect on rate of gain, efficiency of gain, longissimus dorsi area, composition of backfat, creatine phosphokinase levels, or on postmortem muscle pH, color, and firmness.

We concluded that the smaller appetite of the Pietrain than the Spot gilts was not responsible for the inherent tendency toward an unusually high lean proportion in the carcass and soft pale muscle tissue.

Effect of Diet on the Gastrointestinal Tract

Jerome C. Pekas, Ling-Jung Koong, Wilson G. Pond, and Jong-Tseng Yen[1]

Introduction

Meat animal feeding practices vary considerably throughout the world depending on the availability of grain and pasture, on manpower, and on customary animal management practices. Maximum economic performance of meat animals does not always require maximum rate of gain. Market hedging and the availability of inexpensive low energy feedstuffs represent two justifications for feeding animals to obtain less than maximum growth rate. Fluctuation of feed grain prices as currently experienced in the United States justifies management decisions to substitute foodstuffs to optimize economic profit.

At present there is little published information describing how the digestive system responds to substantial changes in either the quality or quantity of diet consumed. The purpose of the studies described in this report was to measure various parameters of the gastrointestinal tract to determine if the gastrointestinal tract responded and the nature and magnitude of the response, if any. We conducted two experiments: (1) the effect of 50 percent alfalfa meal in the diet of growing swine and (2) the effect of drastic changes in level of feed intake to obtain rapid body weight gain or rapid body weight loss in swine.

Procedure

Alfalfa meal in swine diets. Ten genetically obese and 10 genetically lean pigs (Duroc x Yorkshire), initial weight 122-144 lb, were assigned to each of two experimental diets. The reference diet was a conventional corn-soybean (CS) diet; the experimental diet contained 50-percent dehydrated alfalfa meal, which was substituted on a weight basis for corn, and limestone was deleted from the mineral premix. Animals were housed individually in pens with solid concrete floors and fed *ad libitum*. They were slaughtered as they attained 220-lb body weight, and visceral organs were measured immediately after slaughter. Measurements were also obtained from the carcass and wholesale cuts.

Response of the gastrointestinal tract to the level of feed intake. The study was conducted with 27 84-day old pigs, 3 from each of nine litters, which were randomly assigned by litter to three treatment groups. The first group (HL; high-low) was fed to gain 42 lb during the first 35 days (period 1) and to lose 11 lb during the second 35 days (period 2). The second group (MM; medium-medium) was fed to gain 15.5 lb during period 1 and 15.5 lb during period 2. The third group (LH; low-high) was fed to lose 11 lb during period 1 and to gain 42 lb during period 2. At the end of the 70-day experiment, all pigs were to achieve a final weight of 90 lb. The animals were housed and fed individually. Body weight was measured twice weekly. Daily feed allowances were adjusted twice weekly based on the actual body weight and the expected body weight from the predetermined growth curves for each group. Feed was offered once daily, from 8 to 10 a.m.; a conventional CS-growing ration, 16 percent protein, was used throughout.

Results

Alfalfa meal in swine diets. The 50-percent alfalfa meal diet did not suppress feed intake but did suppress the rate and efficiency of gain (Table 1). The alfalfa diet suppressed carcass weight of the wholesale cuts slightly. The alfalfa meal diet did not suppress the longissimus area or the amount of meat obtained from the wholesale cuts, excluding the belly. The effects of the alfalfa on carcass measurements were generally the same for the genetically obese as for the genetically lean pigs; however, there was a tendency for the alfalfa to increase the yield of lean meat (LWSC-TD; Table 1) of the obese but to decrease that of the lean pigs.

The effects of the alfalfa diet on gastrointestinal organs were varied (Table 2). Small intestine weight was increased in lean but not in obese pigs. Small intestine length was decreased in the obese but not in the lean pigs. The weight unit length of the small intestine increased for both obese and lean pigs. The weight of the cecum, pancreas, and liver was not affected by the alfalfa diet in either genotype of pig. The colon-rectum weight was increased markedly by the alfalfa diet in lean pigs but not in the obese. The weight of the heart and spleen was not affected by the alfalfa diet; however, kidney weight was increased.

We conclude from these results that these lean and obese pigs can utilize a high alfalfa diet and grow, although the rate and efficiency of body weight gain were impaired. The most important disadvantage was the additional period the animals remained on the alfalfa diet to obtain the same carcass weight; approximately 60 percent and 40 percent longer feeding periods for the obese and lean genotype pigs, respectively. Another dis-

Table 1.—Means of animal performance and carcass measurements: Means adjusted to final live body weight of 219 lb

Parameter	Corn-soybean		Alfalfa		Stat. sig.[1]
	Obese	Lean	Obese	Lean	
Liveweight:[2]					
Raw----------lb---	219	226	206	225	G
Adjusted----------lb---	219	219	219	219	NS
Performance					
Avg. daily gain ---------lb---	1.57	1.68	.86	1.17	D
Avg. daily feed ---------lb---	7.32	6.86	7.39	7.47	NS
Gain/feed---------- lb/lb---	.21	.23	.12	.16	D
Carcass measurements					
Carcass weight --------lb---	169	158	156	153	D,R
Longissimus muscle area---------- in^2---	3.04	4.76	3.72	4.59	G
Avg. backfat ----------in---	2.48	1.06	2.24	.98	D,G
WSC-UT[3] ----------lb---	77.2	70.5	71.2	67.5	D,G,R
LWSC-T[3]----------lb---	31.3	45.0	34.0	42.3	G,DxG,R
LWSC-TD[3]----------lb---	24.9	36.2	28.2	34.0	G,DxG,R

[1]Statistical significance at $P<0.05$; D = diet; G = genotype; D x G = diet x genotype interaction; R = regression effect (for live body weight adjustment); NS = not significant.

[2]Period of feed for obese-basal, lean-basal, obese-alfalfa, and lean-alfalfa pigs was (days ± standard error): 67 ± 10, 60 ± 16, 106 ± 11, and 81 ± 7; raw and liveweight adjusted values.

[3]Based on measurements taken on the right side of the split carcass; WSC = wholesale cuts, five; LWSC = lean wholesale cuts, four (excludes belly); UT = untrimmed; T = trimmed, all exterior fat removed; TD = trimmed and deboned, all exterior fat and bones removed.

[1]Pekas is a research physiologist, Nutrition Unit; Koong is the research leader, Production Systems Unit; Pond is the research leader and Yen is a research animal scientist, Nutrition Unit, MARC.

Table 2.—Means of gastrointestinal and nondigestive organ weights: Means adjusted to final live body weight of 219 lb[1]

Parameter	Corn-soybean		Alfalfa		Stat. sig.[2]
	Obese	Lean	Obese	Lean	
Gastrointestinal organs					
Stomach, w ----------lb---	0.98	1.12	0.99	1.28	G
Small intestine, w------lb---	2.52	2.43	2.37	2.98	DxG
Small intestine, l -------in---	653.0	631.0	566.0	642.0	D,DxG
Small intestine, w/l ---------- lb/100in---	.39	.39	.42	.46	D
Cecum, w ----------lb---	.32	.26	.38	.36	NS
Colon-rectum, w -------lb---	2.22	2.18	2.39	3.18	D,G,DxG
Colon-rectum, l --------in---	167.0	183.0	163.0	185.0	NS
Colon-rectum, w/l ---------- lb/100in---	1.33	1.20	1.46	1.73	D,DxG
Pancreas, w ----------lb---	.27	.25	.27	.33	NS
Liver, w ----------lb---	2.50	2.57	2.65	2.96	NS
Total gastrointestinal tract----------lb---	8.82	8.80	9.06	11.08	D,G,DxG
Nondigestive organs					
Heart, w----------lb---	.52	.74	.80	.68	G,DxG,R
Spleen, w----------lb---	.19	.34	.21	.29	G
Kidney, w----------lb---	.54	.59	.67	.69	D,R

[1]Abbreviations used: w = weight; l = length; w/l = unit weight/unit length
[2]See Table 1, footnote 1

Table 3.—Effect of different nutritional regimes on gastrointestinal and other organ weights (lb)[1]

Parameter	HL	MM	LH
Stomach----------lb---	[2]0.580	[3]0.633	[4]0.745
Small intestine ------lb---	[2]1.541	[3]1.881	[4]2.233
Large intestine ------lb---	[2].994	[2]1.085	[3]1.296
Pancreas ----------lb---	[2].115	[3].139	[4].174
Liver ----------lb---	[2].986	[3]1.184	[4]1.424
Heart ----------lb---	[2].363	[2].346	[2].342
Kidneys ----------lb---	[2].247	[2].265	[3].306
Spleen ----------lb---	[2].117	[2].112	[2].108

[1]High-low, HL, medium-medium, MM, and low-high, LH, refer to plane of nutrition in 2 periods. All values are means.
[2 3 4]Values not sharing same superscript in same row are significantly different ($P<0.01$).

advantage is that the cutout percentage was reduced by the alfalfa meal. The enlarged gastrointestinal tract of the lean genotype pigs only partially accounts for the reduced cutout percentage. The significance and mechanisms by which the weight or length of the small intestine and colon-rectum changed in size are not understood at this time and will require further investigation.

Response of the gastrointestinal tract to the level of daily feed intake. The final weights of the HL, MM, and LH groups at the end of the 70-day experiment (periods 1 and 2) were the same; this was required in the experimental design. The average daily feed over the 70-day feeding period was 2.33, 2.12, and 1.94 lb/day for the HL, MM, and LH groups, respectively. Although the live body weights of the three treatment groups were the same, the gastrointestinal organ weights from the animals slaughtered immediately after the feeding period were very different (Table 3). Without exception, the weight of the stomach, small intestine, large intestine, pancreas, and liver were the heaviest for the LH group and lightest for the HL group with the MM group being intermediate. These data clearly demonstrate that the digestive organs do respond to the quantity of daily feed intake. In contrast, the weight of the heart and spleen did not respond to the level of daily feed intake; kidney weight followed a trend similar to the digestive organs but of a much lower magnitude.

We conclude that the digestive organs are not static and do not represent a constant proportion of body weight but rather that they were responsive to the quantity of daily feed intake and that the weight of the digestive organs is regulated physiologically and independently of other vital organs. The nature and mechanisms responsible for these profound changes in the gastrointestinal organs are not understood but are presently being investigated.

Effect of Dietary Natural and Synthetic Zeolites on Pig Performance

Wilson G. Pond and Jong-Tseng Yen[1]

Introduction

One of the major avenues for increasing the efficiency of pork production is to improve efficiency of feed utilization inasmuch as feed represents 55 to 85 percent of the total cost of production. During the past 30 years, low levels of antibiotics have been used as feed additives during the growing-finishing period as an effective means of improving body weight gain and efficiency of feed conversion. Such improvements generally are expected to be 5 to 15 percent or more for both weight gain and feed unit weight gain.

Development of strains of bacteria resistant to antibiotics and the possibility of harmful residues of antibiotics in edible tissues of animals fed antibiotics have created concern that antibiotics may be banned by the Food and Drug Administration from use in animal feeds in the United States. Similar rulings are already in effect in several European countries. Such a possibility requires that alternative growth stimulants be developed to replace antibiotics in swine feeds.

Although the beneficial effects of antibiotics on swine performance have been documented over a wide range of environmental conditions, the mode of their action is still unknown. One theory proposed by W. J. Visek, University of Illinois, is that they reduce the population of microbes in the gastrointestinal tract that produces the enzyme urease, which releases free ammonia from urea and other nitrogen-containing compounds. A reduction in the release of ammonia, a potent cell toxicant, would result in a lower energy requirement by the animal to regenerate intestinal epithelial cells and other cells and tissues, thereby making more nutrients available for animal growth. If such a theory is valid, any means by which ammonia release in the gastrointestinal tract can be reduced should result in an improvement in animal performance similar to that obtained with antibiotics.

One such possible approach is the addition to the diet of substances known to bind ammonium ions. A group of substances called zeolites have such ammonia-binding capabilities. Naturally occurring zeolites are three-dimensional aluminosilicate crystalline structures produced in the distant past by appropriate temperature, water, and pressure conditions in volcanic ash erupted from active volcanoes. More than 40 natural zeolites are known, each with specific properties of binding ammonium and other positively charged ions such as calcium, magnesium, potassium, sodium, cadmium, and lead. Of particular interest are zeolites with strong ammonia-binding ability. The natural zeolite, clinoptilolite, has received the most attention due to its requisite binding properties and its widespread occurrence and relative purity in surface deposits of volcanic products.

In addition to natural zeolites, several synthetic zeolites have been developed for specific uses such as in petroleum refining and for home laundry use as components of detergents.

Procedure

Several experiments have been completed to determine the effects of a natural zeolite, clinoptilolite, on performance and metabolism of growing pigs. One experiment has been completed in which clinoptilolite and a synthetic zeolite, zeolite NaA, have been used to determine their effects on the response of young pigs to dietary cadmium, a toxic mineral.

The three experiments reported here were conducted with weanling crossbred pigs fed a standard corn-soybean meal type diet supplemented with clinoptilolite at different levels and from different geographic sources and, in some cases, with ammonium carbonate or antibiotics. In one experiment, diets containing clinoptilolite or zeolite A with or without cadmium were fed. Pigs were penned in groups of two to six and fed the basal and experimental diets *ad libitum*. In some experiments, blood samples were obtained at intervals to measure the concentrations of minerals and other metabolites in plasma.

The experiments were designed to test the following broad hypotheses:

1. The ammonia-binding capacity of clinoptilolite provides a means of alleviating clinical or subclinical ammonia toxicity in pigs.
2. The affinity of specific zeolites for toxic ions (for example, cadmium) provides a means of protecting pigs from adverse effects and tissue uptake of the toxic element.

A preliminary experiment with laboratory rats was completed to establish the effect of clinoptilolite on the toxicity of orally administered ammonium carbonate as measured by the rise in concentration of ammonia in blood carrying nutrients and metabolites from the intestines to the liver (portal vein).

Such experiments require slaughter of the animal; therefore, for preliminary studies, laboratory rats offer a relatively inexpensive animal model for testing ideas. A reduced rise in portal vein ammonia concentration was noted in rats given clinoptilolite along with ammonia, compared with the rise with ammonia given alone. Such data provide evidence for important biological effects of clinoptilolite and suggest the possibility of using clinoptilolite in practical swine feeding. Data obtained elsewhere on pigs have corroborated the results of our rat studies.

Experiment 1. To determine whether continuous dietary intake of ammonium carbonate is associated with reduced body weight gain and feed utilization reversible by clinoptilolite, 32 weanling pigs were assigned at 10 weeks of age to four conventional corn-soybean meal diets containing 0 or 4.0-percent ammonium carbonate or 0 or 5.0-percent clinoptilolite (from Buckhorn, N.Mex. -50 mesh) separately or in combination. Pigs were penned in groups of four and fed the experimental diets *ad libitum* for 19 days; blood was sampled at day 15 for plasma urea nitrogen, ammonia, glucose, and lactate concentrations. Diarrhea scores were made daily on each pen of pigs.

Experiment 2. Fifty-four crossbred castrated male pigs were assigned at 5 weeks of age to six diets containing clinoptilolite from Idaho (-16 or -50 mesh) or New Mexico (granular or -50 mesh) or an antimicrobial agent, Carbadox. Pigs were penned in groups of four and fed *ad libitum* for 28 days. We then recorded individual body weight gains and feed consumed by each pen of pigs.

Experiment 3. Thirty-six crossbred weanling pigs were assigned at 5 weeks of age to six diets containing no zeolite, synthetic zeolite NaA, or natural zeolite (clinoptilolite, Idaho fine, -50 mesh) or the same three diets to which cadmium chloride (150 ppm) was added to provide 92 ppm of dietary cadmium. Pigs were penned three per group and fed *ad libitum* for 31 days. Blood was sampled from each pig at days 14 and 28 to determine hemoglobin and hematocrit and plasma mineral concentrations. All pigs were slaughtered on day 31; livers and kidneys were removed to measure cadmium, zinc, calcium, magnesium, iron, manganese,

[1]Pond is the research leader and Yen is a research animal scientist, Nutrition Unit, MARC.

and copper concentrations.

Results

Experiment 1. Daily weight gain, gain/feed, diarrhea scores, and 15-day blood plasma urea nitrogen, ammonia, glucose, and lactate concentrations are summarized in Table 1. Daily weight gain was less in pigs fed both ammonium carbonate and clinoptilolite than in those fed the basal diet; daily gain of pigs fed diets containing either additive alone was intermediate. Gain/feed did not differ among groups, although pigs fed diets containing clinoptilolite tended to convert feed to body weight gain less efficiently than those not fed clinoptilolite. Diarrhea was not a major problem in any dietary group, but pigs fed ammonium carbonate in the absence of clinoptilolite appeared to have persistent minor diarrhea not present when clinoptilolite was added to the diet with ammonium carbonate. Blood plasma ammonia, glucose, and lactate at day 15 were not affected by either ammonia or clinoptilolite; plasma urea nitrogen was higher in pigs fed ammonium carbonate than those not fed it. Although the mean concentration was less in plasma of pigs fed clinoptilolite than in those not fed it, either in the presence or absence of ammonium carbonate, the difference was not significant.

Experiment 2. Daily body weight gain and weight gain/unit feed consumed are summarized in Table 2. Feed consumption of pigs fed 5-percent clinoptilolite (diets 3 to 6) was adjusted to account for the energy dilution of those diets. Pigs fed Idaho coarse clinoptilolite had lower daily weight gains than those fed all other diets; pigs fed New Mexico fine and coarse clinoptilolite had lower daily gain than pigs fed the basal diet or the diet containing Idaho fine clinoptilolite. Carbadox failed to improve daily gain; this was in agreement with some but not all previous experiments at MARC in which the effect of dietary Carbadox was tested. The Idaho fine source, which produced the fastest weight gain (although not different from that of pigs fed the basal or Carbadox-supplemented diet), appeared not to contain quartz. Other differences between the clinoptilolite sources used such as potassium, calcium, magnesium, or iron contents are possible factors affecting differences in observed animal responses.

Experiment 3. No significant effect of diet was noted on daily weight gain, although pigs fed clinoptilolite tended to gain faster than other groups (1.0 and 0.9 lb daily for pigs fed the 3-percent clinoptilolite diet, and basal diet, respectively). Hemoglobin and hematocrit were reduced significantly by dietary cadmium. Adding 3-percent clinoptilolite or zeolite A to the diet partially prevented these reductions. Liver zinc was reduced by dietary cadmium; zeolite A increased liver zinc concentration both in the presence and in the absence of dietary cadmium. Liver cadmium was increased by dietary cadmium, but the magnitude was less in pigs fed clinoptilolite than in other pigs receiving cadmium.

Ammonia-binding experiments. The ammonia-binding property of clinoptilolite *in vivo* was illustrated in a preliminary experiment in which portal vein blood ammonia concentration of rats dosed orally with a toxic amount of ammonia (45 or 90 mg of ammonium carbonate/100 g body weight) rose less in the presence of clinoptilolite than in its absence. In a series of three experiments in which ammonium carbonate was added to the diet of growing swine (experiment 1 of this report) or pregnant rats, the presence of clinoptilolite failed to produce beneficial effects and, in fact, reduced body weight gain compared to that obtained when ammonium carbonate was added alone. This response is interpreted as evidence that dietary ammonium ion was bound by clinoptilolite in the upper gastrointestinal tract and subsequently released and converted partly to free ammonia in the lower gastrointestinal tract where it may have been absorbed as free ammonia. Such a phenomenon could explain the adverse effect of clinoptilolite and ammonium carbonate together in the diet on animal growth in view of the known toxicity of ammonia. Microorganisms can use ammonia for synthesis of amino acids and proteins, but release of ammonia in the large intestine, which is beyond the site of maximal amino acid absorption, would limit the availability to the host of amino acids that the microbes synthesize. In growing pigs, clinoptilolite appeared to alleviate the diarrhea encountered when ammonium carbonate was fed. Blood plasma urea nitrogen was lower in growing pigs fed diets containing clinoptilolite, either in the presence or absence of ammonium carbonate, suggesting that ammonia nitrogen released by urea hydrolysis in the gastrointestinal tract was bound by clinoptilolite to reduce the load of ammonia reaching the liver for detoxification.

The difference between Idaho and New Mexico clinoptilolite in affecting daily weight gain of pigs in experiment 2 could be related in some way to the nature of the impurities in fine compared with coarse samples of clinoptilolite from the same and different sources. Idaho fine source, which produced the fastest mean weight gain, had a lower potassium and iron content than the Idaho coarse, and the fine and coarse New Mexico sources had a higher sodium-to-potassium ratio than the Idaho coarse clinoptilolite. The degree of purity was greater in Idaho (72 pct) than in New Mexico (58 to 62 pct) clinoptilolite.

A major potential application of zeolites in animal nutrition has been considered to be that of binding ammonium ions in the gastrointestinal tract. Intestinal microflora contribute to the concentration of ammonia entering the blood through their action in deamination of ingested protein and urea hydrolysis. A suggested mode of action of the growth promotion by subtherapeutic levels of dietary antibiotics in animals is that of suppressing gastrointestinal microorganisms, which produce urease that hydrolyzes urea to ammonia. The failure of clinoptilolite to improve weight gain of growing pigs cannot be considered as evidence for lack of its efficacy for use as a diet supplement because Carbadox, an antimicrobial agent that usually stimulates weight gain, also failed to improve performance in these experiments. Further work is needed with animals kept in an environment expected to allow a positive response to antibiotics to adequately test the efficacy of zeolites as growth promotants for swine.

The reduced blood hemoglobin and hematocrit in pigs fed 92-ppm cadmium as cadmium chloride were expected from past research. The presence of clinoptilolite or zeolite A in the diet partially prevented this cadmium-induced anemia, suggesting that some of the cadmium was effectively bound so that it was biologically inactive in interfering with iron absorption. The accumulation of cadmium in the liver of cadmium-fed pigs was expected; the lower concentration of cadmium in the livers of pigs fed clinoptilolite indicates some protection against cadmium absorption associated with the cadmium-binding properties of clinoptilolite. Zeolite A failed to affect liver cadmium concentration despite its known cadmium-binding ability. This failure may have been related to its partial destruction in the acid environment of the stomach; the protection of zeolite A against cadmium-induced anemia observed in this experiment suggests important biological properties of zeolite A, even though it failed to reduce liver storage of cadmium at the level of exposure (92 ppm in the diet) used in this experiment. The data suggest that zeolite A increases liver zinc concentration either in the presence or absence of dietary cadmium. The biological importance of this effect of zeolite A on zinc metabolism needs further study.

Table 1.—Effect of ammonium carbonate on the response of weanling pigs to dietary clinoptilolite—Experiment 1

Item	Diet no.:	1	2	3	4
	Diet designation:	Basal (B)[1]	B + Ammonia (A)[2]	B + Clinoptilolite (C)[3]	B + A + C
No. pigs[4]		8	8	8	8
Daily gain, lb[5]		[1]1.61	[1 2]1.40	[1 2]1.35	[2]1.27
Gain/feed		.291	.352	.236	.222
Diarrhea score[6]		0	22.0	3.0	4.0
Blood plasma traits on day 15:					
Ammonia, mg/dl		.45	.42	.51	.46
Glucose, mg/dl		110.0	100.0	113.0	103.0
Lactate, mM/dl		4.7	4.0	5.5	5.7

[1]Corn-soybean meal type diet.
[2]Ammonium carbonate replaced dextrose at 4 percent.
[3]Clinoptilolite from Buckhorn, N. Mex. (–50 mesh) replaced dextrose at 5 percent.
[4]Two replicate pens of 4 pigs fed each diet; avg. initial body weight 56 lb; 10 weeks old; 19-day experiment.
[5]Means in the same row without a common superscript differ ($P<0.01$).
[6]Days x pen score (score: 0 = normal, 1 = slight diarrhea normal; 1 = slight diarrhea; and 2 = severe diarrhea).

Table 2.—Effect of dietary clinoptilolite particle size and geographic source on body weight gain and feed utilization of growing swine—Experiment 2

Item	Diet no.:	1	2	3	4	5	6
	Diet designation:	Basal[1]	Carbadox	ID fine[2]	ID coarse[3]	NM fine[4]	NM coarse[5]
No. of pigs		9	9	9	9	9	9
Daily gain, lb[6]		[1]1.34	[1 2]1.31	[1]1.35	[3]1.21	[2]1.28	[2]1.27
Adjusted gain/feed[7]		.46	.48	.47	.45	.46	.43

[1]Corn-soybean meal type diet.
[2]Idaho fine (–50 mesh).
[3]Idaho coarse (–16 mesh).
[4]New Mexico fine (–50 mesh).
[5]New Mexico coarse (granular).
[6]Means in the same row without a common superscript differ ($P<0.01$).
[7]Feed intake of animals fed 5 percent clinoptilolite (diets 3 to 6) was multiplied by 0.95 before gain/feed composition to account for the energy dilution of these diets by clinoptilolite.

Response of Lean and Obese Swine to Protein Depletion and Repletion

Wilson G. Pond, Jong-Tseng Yen, and Harry J. Mersmann[1]

Introduction

A major portion of the cost of swine feeding is that of adequate protein supplementation. In the United States, the typical diet is composed of corn and cereal grains and their by-products plus soybean meal and vitamin and mineral fortification. There is economic incentive to minimize protein supplement use; however, severe restriction of protein intake results in reduced growth and efficiency of feed utilization. The young pig has been used widely as a model for studying the effects of protein deficiency on human development and on swine production efficiency.

Protein restriction, but not energy restriction, in early postweaning life of the pig, reduces serum total protein and albumin. Energy-restricted pigs have a greater ability to recover from the deficit than protein-restricted pigs as measured by weight gains during rehabilitation.

Two experiments have been completed at MARC to determine the effect of early postweaning growth retardation induced by dietary protein restriction on subsequent growth and carcass measurements of pigs differing in genetic propensity for fattening. Determining whether body composition affects the protein requirement for growth is important to provide a basis for balancing the protein-energy ratio in diets for pigs of differing genetic backgrounds.

Procedure

Two experiments were completed with pigs selected for 20 generations for low- or high-backfat thickness. The original population consisted of purebred Duroc and Yorkshire pigs located at USDA's Agricultural Research Center at Beltsville, Md. Within each breed, breeding animals were selected based on backfat thickness for leanness or obesity; when these selected lean (L) and obese (O) lines were transferred from Beltsville to MARC in 1976, the purebreds were crossed within L and O selected lines to form the crossbreed L and O lines used in the current studies.

Experiment 1. Sixteen genetically O female Duroc x Yorkshire and 16 L female Hampshire x Yorkshire contemporary pigs were assigned within two replicates of each genetic group at 4 weeks of age to conventional corn-soybean meal diets, one containing 78-percent corn and 4-percent soybean meal to total 12 percent protein (LP), the other containing 57-percent corn and 25-percent soybean meal to total 18-percent protein (HP). Amino acid ratios were not held constant. Pigs were penned in groups of 4 for 8 weeks in a temperature-controlled building; at 8 weeks (12 weeks of age), pigs fed LP were transferred to a standard diet and fed *ad libitum* to slaughter. All pigs were weighed biweekly, and feed consumption of each pen of pigs was recorded. Blood was sampled from one-half of the pigs in each diet group at weeks 8, 12, 16, and 18 for hemoglobin, hematocrit, serum total protein, albumin, and transferrin determination. Backfat thickness was estimated by ultrasonic probe at weeks 12, 16, and at slaughter, and carcass length and longissimus muscle cross-sectional area were measured at slaughter.

Experiment 2. Ninety-four progeny of O, L, and contemporary swine fed an adequate diet (4.0 lb/animal daily) or restricted diet (1.32 lb/animal daily) during the first two-thirds of pregnancy were assigned within genetic background and dam diet group to an adequate protein diet (18 pct) or a restricted protein diet (9 pct) fed *ad libitum* from weaning (4 weeks of age) to 10 weeks of age. At 10 weeks of age, half of the pigs in each group (3 genetic groups x 2 dam energy levels x 2 pig protein levels = 12 groups) were slaughtered, and the remainder were continued on a standard 18-percent protein diet fed *ad libitum* to approximately 5 months of age.

Pigs were weighed at weeks 4, 6, 8, and 10, and those continued beyond 10 weeks were weighed monthly to slaughter. Blood was obtained from the anterior vena cava of each pig at weeks 4, 6, 8, 10, and 14 and analyzed for hematocrit and for plasma total protein and albumin concentrations. The following carcass measurements were taken on animals slaughtered at 10 weeks of age: carcass weight, carcass length (anterior edge of first rib to anterior edge of pubic bone), cross-sectional area of the longissimus muscles (left and right) at the interface of the 10th and 11th ribs, cross-sectional area of subcutaneous backfat at the 10- to 11-rib interface, midline backfat thickness over first and last ribs and last lumbar vertebrae, weight of liver, kidneys, adrenals, thyroid, heart, and gastrocnemius muscle (GM). Dry matter content of liver and GM and protein in dry matter of GM were determined by freeze-drying and Kjeldahl, respectively. Carcass weight, length, backfat thickness (average of first rib, last rib, and last lumbar vertebrae), and cross-sectional area of the longissimus muscle at the 10- to 11-rib interface were recorded in animals slaughtered at 5 months, and heart, liver, and kidney weights were recorded. Feed intake of each pen of pigs from 4 to 10 weeks of age and from 10 weeks to slaughter was recorded.

Results

Experiment 1. Body weight gain, feed consumption, and feed/unit gain are summarized in Table 1. Protein deficiency depressed performance during the 8-week depletion period. Obese pigs fed low protein gained weight more than twice as fast as L pigs (0.42 vs 0.17 lb/day) fed low protein. During the repletion phase, daily gain was not affected by previous dietary protein level. The weight curves during the 10-week repletion phase of L pigs and O pigs fed low protein versus control diets during the 8-week depletion phase suggest that compensatory growth does not occur in L pigs but may occur in O pigs under the experimental conditions imposed. The body weight curves of O and L pigs during protein depletion and repletion are shown in Figure 1. Carcass data are shown in Table 2.

The more severe effect of early protein deficiency on body weight gain of genetically L pigs than shown in O pigs is in agreement with previous results. The greater reduction in serum albumin in L pigs fed low protein than shown in O pigs fed low protein for 8 weeks supports the concept of a higher protein requirement of L than of O pigs for growth. Serum transferrin concentration was reduced in protein deficient animals but was restored to normal within 4 weeks of repletion, suggesting that this metabolite may be a useful indicator of protein status.

Experiment 2. Body weight to 10 weeks and carcass data are summarized in Table 3 for pigs slaughtered in experiment 2. Energy intake of the dam during the final two-thirds of gestation adversely affected 4-week weight of progeny of C dams but not of O or L dams (genetic x sow energy interaction); body weight by breed group was C>O>L. The genetic x sow energy (G x E) interaction persisted through 4-weeks postweaning. Protein restriction reduced weight gain beginning 2-weeks postweaning, and the effect persisted through 10 weeks. Maternal energy

[1]Pond is the research leader and Yen is a research animal scientist, Nutrition Unit; and Mersmann is a research chemist, Meats Unit, MARC.

Table 1.—Effect of early dietary protein deficiency on weight gain and subsequent growth performance of lean and obese pigs

Item	Genetic group: / Diet:	Obese		Lean	
		Low protein	Control	Low protein	Control
No. of pigs		8	8	8	8
Body wt after 8 weeks depletion	lb	35.0	66.0	23.0	69.0
Daily gain, depletion	lb	.42	.97	.17	.96
Feed/gain, depletion[1]		2.94	1.97	4.76	1.83
Body wt at slaughter	lb	194.0	207.0	207.0	213.0
Daily gain, repletion	lb	1.39	1.28	1.60	1.70
Feed/gain, repletion[1]		4.00	4.40	3.16	3.50
Daily gain, overall	lb	1.07	1.17	1.13	1.42

[1]Two pens of 4 pigs/diet (total of 8 pens), initial body wt 13 lb.

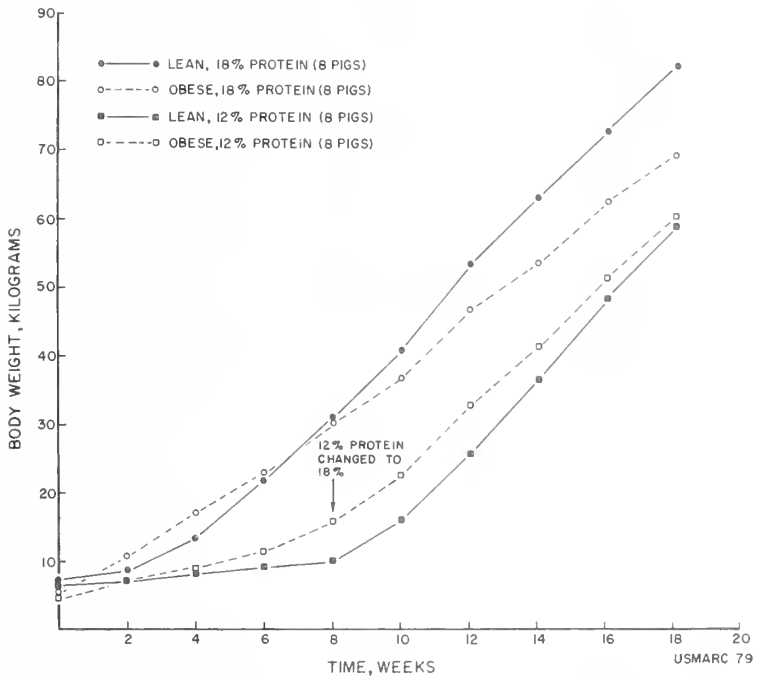

Figure 1—Effect of dietary protein restriction from 4 to 12 weeks of age on body weight gain of lean and obese pigs to 22 weeks of age.

Table 2.—Effect of early dietary protein deficiency on carcass measurements of lean and obese pigs

Item	Genetic group: / Diet:	Obese		Lean	
		Low protein	Control	Low protein	Control
No. of pigs		8	8	8	8
Carcass length	in	27.5	28.0	31.4	31.2
Ultrasonic backfat, in:					
12 weeks		.76	.98	.33	.39
16 weeks		1.58	1.62	.86	.93
Slaughter		6.46	6.09	2.70	2.26
Rule back fat, in:					
Slaughter		2.49	2.64	.98	.93
Longissimus muscle area	in^2	3.9	3.8	5.8	6.7

Table 3.—Effect of maternal gestation energy intake and postweaning piglet dietary protein level on body weight and carcass measurements

Item	Genetic group:	Obese				Lean				Contemporary			
	Sow energy:	Adequate[1]		Restricted[2]		Adequate		Restricted		Adequate		Restricted	
	Pig protein:	HP[3]	LP[4]	HP	LP	HP	LP	HP	LP	HP	LP	HP	LP
Pigs slaughtered at 10 weeks of age													
No. of pigs		4	3	4	4	4	4	3	4	4	5	4	4
Body wt	lb	29.3	11.7	34.8	13.2	28.6	10.3	34.1	10.8	46.9	20.9	33.4	14.1
Carcass wt	lb	22.4	8.4	25.5	9.7	21.1	7.3	26.0	7.9	34.8	13.9	23.1	9.9
Carcass wt, percent of body wt		76.4	71.4	73.5	71.8	73.5	68.8	73.8	71.9	73.5	66.5	68.9	69.7
Carcass length	in	16.6	12.6	15.5	13.0	16.8	12.0	17.5	12.6	20.6	16.0	18.2	13.3
Longissimus muscle	in^2	1.83	1.23	2.32	.98	1.81	.69	1.92	.47	2.70	.99	1.98	.66
Backfat depth	in	.72	.41	.80	.44	.48	.29	.45	.24	.57	.35	.45	.32
Pigs slaughtered at 5 months of age													
No. of pigs		2	3	6	2	3	2	4	4	4	4	4	4
Initial body wt	lb	40.0	16.7	40.3	12.5	31.5	11.2	20.9	12.1	62.2	23.1	51.5	23.1
Final wt	lb	163.9	134.9	172.3	145.2	144.1	95.7	134.9	126.5	207.9	146.2	209.7	171.2
Daily gain	lb	1.20	1.17	1.32	1.29	1.15	.79	1.22	1.11	1.70	1.46	1.81	1.68
Feed/day		5.08	4.22	5.10	4.62	3.85	2.77	4.29	3.17	5.54	4.16	5.59	4.42
Gain/feed		.10	.11	.10	.11	.12	.09	.11	.13	.12	.14	.13	.15
Backfat	in	2.3	2.0	1.9	1.9	.8	.4	1.3	.8	1.0	.9	1.2	1.1
Longissimus muscle	in^2	.30	.19	.27	.21	.36	.18	.28	.25	.46	.37	.40	.33
Carcass length	in	63.4	62.3	63.2	64.5	69.7	53.9	63.2	63.5	78.2	70.3	76.8	72.2
Carcass wt	lb	114.8	91.1	112.6	97.2	94.4	44.0	87.6	77.4	141.0	105.8	140.4	110.7
Carcass wt, percent of body wt		70.0	67.5	67.5	66.9	65.5	64.6	64.8	65.8	67.9	67.6	66.7	64.3

[1]Adequate gestation energy = 4 lb feed/animal daily.
[2]Restricted gestation energy = 1.3 lb feed/animal daily during final 2/3 of pregnancy.
[3]High protein (18 pct) fed to progeny postweaning (4 to 10 weeks of age).
[4]Low protein (9 pct) fed to progeny postweaning (4 to 10 weeks of age).

restriction also reduced pig postweaning weight gain at 8 and 10 weeks of age in L and C but not in O pigs. There was an adverse effect of postweaning protein restriction and a G x E interaction at 10 weeks of age. Carcass weight at 10 weeks was reduced by protein restriction in absolute terms but not when expressed as a percentage of body weight. Genetic background had no effect on carcass weight. Carcass length was greater in C than in O or L pigs and was reduced by pig protein restriction. Longissimus muscle area and backfat area were decreased, and backfat depth was decreased by pig protein restriction; backfat area and depth were greater in O than in L or C pigs.

Hematocrit was higher in L than in O or C pigs at weaning while O pigs had higher hematocrit at 6, 8, and 10 weeks than pigs of other genetic backgrounds. There was no effect of dam energy intake on pig hematocrit at any sampling period; L and C pigs but not O pigs fed restricted protein had lower hematocrit at 8 weeks than genetically matched pigs fed high protein, resulting in a G x Pr interaction. At week 10, hematocrit was depressed in pigs fed low protein regardless of genetic background; mean hematocrit of O pigs was greater than that of L and C pigs.

Plasma total protein (PTP) and albumin (PA) showed similar trends; PTP and PA were higher in O than in L and C pigs at all sampling times (4,6,8, and 10 weeks). Dam gestation feed restriction was associated with lower PTP and PA than adequate feed intake in all genetic groups at 4 weeks of age. This effect persisted for PTP at weeks 6, 8, and 10 and for PA at weeks 8 and 10. PTP and PA concentrations were reduced by low postweaning dietary protein within 2 weeks after weaning, and the effect persisted in all three genetic groups to 10 weeks of age. Also, PA was depressed more by protein restriction in pigs from dams fed adequate energy than from those severely restricted dams. Average daily gain (ADG) for the pigs slaughtered at 5 months was greater in C than in L or O pigs; pigs fed adequate protein gained faster than those fed restricted protein for 6 weeks postweaning. Pigs from dams fed restricted energy during gestation gained faster than those from adequately fed dams. Gain/feed was greater for C than for O and L pigs. Backfat (BF) was greater in O than in L or C pigs; prior protein restriction reduced BF in L and C pigs; energy restriction of the dam during gestation resulted in greater BF in progeny at 5 months of age in L and C but not O pigs.

An effect of severe maternal energy restriction during gestation on subsequent growth of the progeny was apparent only in C pigs, perhaps as a reflection of the greater growth rate of C pigs than of O or L pigs postweaning. The sustained adverse effect on weight gain to 10 weeks of age of severe feed restriction of C gilts during the last two-thirds of pregnancy is similar to that observed in Yorkshire gilts deprived of all feed during the middle or last third of pregnancy. The adverse effect of pregnancy energy restriction on mammary development is generally recognized in food animals. The smaller effect on progeny of O and L gilts in the present experiment illustrates the importance of genetic background on response to gestation feed restriction.

The two experiments reported here demonstrate the importance of genetic background in affecting the response of growing pigs to dietary protein restriction and to maternal energy intake. These differences appear to be due to a higher protein requirement of lean than of obese pigs.

Influence of Dietary Fiber on Performance and Large Intestinal Microflora of Growing-Finishing Swine

Vincent H. Varel and Wilson G. Pond[1]

Introduction

The digestibility and utilization of highly fibrous feeds is generally associated with ruminant animals instead of monogastrics such as swine. Evidence shows, however, that the ability of the pig to utilize dietary fiber may be underestimated. Digestibility of fibrous material, much of which is in the form of cellulose, is due to bacterial action as it occurs in the large intestine. Cellulose is broken down to products called volatile fatty acids such as acetate, propionate, and butyrate. These products are then presumed to be absorbed from the large intestine and used as an energy source by the animal. One method to determine if cellulose is being digested in the large intestine is to determine the number of cellulose-digesting bacteria present there and to determine the extent of their activity by assaying for the enzyme, cellulase. The objective of the present study was to determine growth, carcass characteristics, and number and activity of cellulose-digesting bacteria found in intestinal samples from pigs fed either a low- or high-fiber diet.

Procedure

Sixteen finishing littermate crossbred barrows averaging approximately 55-lb body weight were divided equally and fed either a low- or high-fiber diet (0 or 35-percent dehydrated alfalfa meal, respectively) for 70 days. Number and activity of cellulose-digesting bacteria from rectal samples and animal growth characteristics were determined periodically during the trial. Carcass measurements were obtained at slaughter.

Results

Pigs fed the high-fiber diet had a 17.3 percent less average daily gain (ADG) and a carcass weight 14.3 percent less than the pigs fed the low-fiber diet (Table 1). Thickness of backfat and rib eye area was significantly less from the pigs fed the high-fiber than the low-fiber diet. We found that even though ADG was significantly less with the high-fiber diet, our main objective in this study was to observe a contrast in cellulolytic activity between the two groups of pigs; thus, we selected a level of fiber (35 pct) that might ensure us of this at the consequence that performance may be reduced. A diet containing approximately 20-percent alfalfa generally would not reduce ADG in growing-finishing pigs. This level can be as high as 97 percent for sows with satisfactory reproductive performance being maintained.

The overall mean number and activity of the cellulolytic bacteria were greater in the pigs fed the high-fiber diet compared to the low-fiber diet (Table 2). Some variability can be expected in the number of cellulolytic bacteria/sample, although we do not know why on days 53 and 67 to 70 with the high-fiber diet pigs the number declined. We speculate that during days 67 to 70 (slaughter) the pigs on the high-fiber diet were without feed for 1 day, which may explain the lower values, 33.6 and 37.98, for the cellulolytic number and activity, respectively, during this period. The results indicate, however, that the cellulolytic bacterial flora respond to the high-fiber diet in a positive manner by increasing their number and activity.

During the 70-day feeding trial, a significantly lower concentration of organic acids and ammonia, along with a significantly higher acetate-to-propionate ratio, was observed in samples from the pigs fed the high-fiber diet (Table 3). This indicates that diet significantly modified bacterial metabolism, in general, in the large intestine of the pigs. The higher acetate-to-propionate ratio observed in the pigs fed the high-fiber diet was due to a decrease in propionate production. This coincides with what takes place in the rumen when a high-forage diet is fed.

Whether or not pigs can utilize the modified volatile fatty acids in an efficient manner requires further research. Propionate is produced in the rumen and used more efficiently by the ruminant than acetate. Assuming propionate is absorbed and then metabolized more efficiently than acetate in the lower tract of the pig, this, along with the lower total organic acids present, could in part explain the reduced performance of these pigs compared to the pigs on the low-fiber diet.

In summary, we observed reduced weight gain with less backfat on the pigs fed the 35-percent alfalfa diet. The cellulolytic bacterial numbers and activity responded in a positive manner to the high-fiber diet, indicating the potential of developing increased cellulose digestion capability with continuous feeding of a high-fiber diet. This could be important, in particular, with the rearing and long-term maintenance of sows used for reproduction.

[1]Varel is a research microbiologist and Pond is the research leader, Nutrition Unit, MARC.

Table 1.—Comparison of growth characteristics and carcass measurements of pigs fed diets containing low- or high-fiber[1]

Parameter	Diet	
	Low-fiber	High-fiber
No. pigs	8	8
Initial weight, lb	65.0 ±2.9	63.6 ±2.6
Slaughter weight, lb	[2]185.2 ±5.1	[3]164.2 ±5.3
Days on diet	63	63
Overall average daily gain, lb	[2]1.91 ± .04	[3]1.58 ± .13
Feed consumed/day/pig, lb	5.50 ± .64	5.26 ± .75
Feed to gain ratio	[2]2.87	[3]3.33
Hot carcass weight, lb	[2]128.2 ±3.1	[3]109.9 ±3.7
Backfat thickness		
1st rib, in	[2]1.91 ± .06	[3]1.24 ± .10
Last rib, in	[2].88 ± .07	[3].51 ± .06
Last lumbar, in	[2]1.19 ± .10	[3].74 ± .07
Rib eye area, 10th rib, in^2	[2]4.5 ± .19	[3]3.6 ± .08

[1]Data given as mean ± SEM.
[2,3]Means within a treatment without a common superscript differ ($P<0.05$).

Table 2.—Comparison of number and activity of cellulolytic bacteria from rectal samples of pigs fed diets containing low- or high-fiber[1]

Time on diet (days)	Cellulolytic bacteria ($X 10^7$/g dry wt)		Cellulase activity (mg glucose released/g dry wt/30 min)	
	Low-fiber	High-fiber	Low-fiber	High-fiber
0	47.7 ±13.5	[2]50.2 ±11.1	29.92 ±2.15	[2]25.52 ±1.84
5	33.7 ±11.4	37.9 ± 9.8	28.66 ±2.94	20.16 ±1.98
11	26.6 ± 4.2	76.2 ±23.0	29.01 ±1.95	29.89 ±8.29
18	60.2 ±17.8	108.8 ±20.7	29.42 ±3.20	33.51 ±7.69
32	27.6 ± 8.5	97.5 ±27.2	29.73 ±1.19	41.74 ±6.21
53	46.3 ±16.2	45.7 ±11.9	29.74 ±4.27	39.23 ±6.71
67 to 70	52.6 ±16.8	33.6 ± 7.4	19.91 ±2.31	37.98 ±5.39
Overall	[3]41.1 ±6.53	[4]66.6 ±8.14	[3]27.72 ±1.27	[4]33.75 ±2.81

[1]Data given as mean ± SEM.
[2]Low-fiber diet.
[3,4]The overall means within each assay without a common superscript differ ($P<0.05$).

Table 3.—Comparison of total organic acids, acetate to propionate ratios, and ammonia nitrogen concentrations from rectal samples of pigs fed diets containing low- or high-fiber[1]

Time on diet (days)	Total organic acids (g acetate/liter)		Acetate to propionate ratio		Ammonia-N (mg/g dry wt)	
	Low-fiber	High-fiber	Low-fiber	High-fiber	Low-fiber	High-fiber
0	2.36 ±0.11	[2]2.51 ±0.14	1.92 ±0.06	[2]1.90 ±0.09	1.46 ±0.20	[2]1.16 ±0.24
5	2.28 ± .16	2.02 ± .07	1.96 ± .08	2.59 ± .06	1.45 ± .30	.81 ± .18
11	2.54 ± .18	1.7 ± .05	1.73 ± .05	2.70 ± .11	1.85 ± .37	.74 ± .12
18	2.33 ± .09	1.6 ± .09	1.94 ± .08	2.68 ± .09	1.90 ± .22	.55 ± .08
32	2.5 ± .19	2.38 ± .13	1.72 ± .09	2.32 ± .14	2.60 ± .24	1.24 ± .11
53	2.61 ± .15	2.28 ± .11	1.87 ± .11	2.40 ± .13	2.90 ± .28	1.25 ± .14
67 to 70	2.19 ± .12	1.84 ± .09	2.31 ± .16	2.18 ± .13	2.91 ± .25	1.28 ± .09
Overall	[3]2.4 ± .07	[4]1.98 ± .05	[3]1.92 ±0.05	[4]2.48 ±0.05	[3]2.27 ±0.14	[4]0.98 ±0.07

[1]Data given as mean ± SEM.
[2]Low-fiber diet.
[3,4]The overall means within each assay without a common superscript differ ($P<0.05$).

Effects of Body Composition on Postweaning Maintenance Requirements in Pigs

Michael W. Tess, Gordon E. Dickerson, Calvin L. Ferrell, and John A. Nienaber[1]

Introduction

In most pork production units, feed energy is the largest single input; hence, efficiency of feed energy utilization is closely associated with production efficiency. An understanding of the components of energy utilization permits more accurate predictions of energy requirements and identifies the components that are potentially sensitive to genetic and environmental change or both.

The maintenance requirement for growing animals (ME_M) may be defined as the metabolizable energy intake required in excess of that required for the deposition of protein and fat. It (ME_M) is generally assumed to be directly related to temporary fasting heat production (FHP). Both FHP and ME_M have been commonly predicted from the 0.75 power of liveweight ($LWT^{0.75}$). Other research reports have demonstrated that the relationship between $LWT^{0.75}$ and ME_M or FHP may be different for fat than for lean pigs. In this study, large genetic differences among three stocks in the composition and rate of growth were used to investigate the effects of body composition on FHP.

Procedure

Ten sets of three littermate barrows from each of three genetic stocks (Beltsville high-fat and low-fat Duroc-Yorkshire composites and a Hampshire x Large White cross) were used in a comparative slaughter and calorimetry experiment. Pigs were full-fed a 16-percent crude protein, corn-soybean diet throughout the experiment. At 10, 17, and 24 weeks of age, one pig from each set was fasted for 24 h before measuring oxygen consumption and carbon dioxide production for 24 h in an open circuit calorimeter. Fasting heat production was calculated from the oxygen consumed and carbon dioxide produced during quiet night hours 38 to 46 after initiation of fast. Temperatures in the calorimeters were 65.3°F at 10 weeks, but increased to 76.3° and 77.0° at 17 and 24 weeks, respectively. Each pig was then slaughtered and analyzed chemically for water, protein, fat, and ash.

Results

Correlations among FHP, LWT, lean (nonfat weight), water, protein, and fat were calculated separately for pigs slaughtered at 10, 17, and 24 weeks (Table 1). Correlations of FHP with LWT and the body components were generally lower at 10 weeks than at 17 or 24 weeks. At each age, correlations between FHP and LWT were lower than those between FHP and the nonfat components (lean, water, and protein). Most striking were the low correlations between FHP and fat, indicating that fat was of little value in predicting FHP. The extremely high correlations among lean, water, and protein indicate that these variables were interdependent, essentially alternative measures of the nonfat portion of the body.

Alternative regression equations were calculated from the data to find the best predictors of FHP at each age. Regressions calculated were of two types: linear and nonlinear. Lean, water, and protein were not included in the same equation because of their interdependence (Table 1). The "best" regression was the one with the smallest residual error variance and with all coefficients significantly different from zero.

The best prediction equations based upon LWT, lean, and fat are listed in Table 2. Regressions based upon water and protein were similar in accuracy to those based upon lean and have been omitted from the table. Regression coefficients were much higher at 10 weeks than at 17 or 24 because of the cooler calorimeter temperature at 10 weeks (65° vs 76° or 77° F).

Prediction equations based upon lean mass had higher R^2 values than those based upon LWT at each age period, and thus explained more of the observed variation in FHP. Nonlinear regression equations, using the appropriate power of component weight, were similar in accuracy to the linear equations.

The negative partial regression on fat detected at 17 weeks suggests that pigs with equal amounts of lean tissue produced less heat if they were fatter. Partial regressions on fat calculated at 10 weeks also were negative but not significant while partial regressions on fat calculated at 24 weeks were positive but not significant. These results suggest that the younger (and smaller) 10-week-old pigs may have been below their critical temperatures in the calorimeters.

Results from this study suggest that FHP of growing pigs fed *ad libitum* is almost completely determined by their lean mass. Body fat stores are apparently maintained at little energy cost. Since FHP is generally assumed to be proportional to ME_M, these results suggest that ME_M is primarily determined by the lean mass of the pig in the absence of environmental stress.

The energy cost above ME_M for growth of lean tissue is much lower than for growth of fat tissue because of the large amount of water contained in the lean tissue. Selection of breeding stock, therefore, for leanness should yield a desirable correlated response in feed conversion. The results of this study, however, indicate that such correlated responses may be reduced due to the associated increases in ME_M. Furthermore, selection for leanness may lead to higher maintenance costs for breeding females.

[1]Tess is assistant professor of animal science, North Carolina State University (formerly MARC-supported Ph.D. student at the University of Nebraska–Lincoln); Dickerson is a research geneticist, Genetics and Breeding Unit; Ferrell is a research chemist, Nutrition Unit; and Nienaber is an agricultural engineer, Agricultural Engineering Unit, MARC.

Table 1.—Correlations (r) among fasting heat production (FHP), liveweight (LWT), and weights of body components within age groups

Variable	LWT	Lean	Water	Protein	Fat
10 weeks (30 pigs):					
FHP	[1]0.72	[1]0.76	[1]0.76	[1]0.73	0.03
LWT		[1].92	[1].91	[1].96	[1].45
Lean			[1]1.00	[1].98	.19
Water				[1].96	.16
Protein					.36
17 weeks (29 pigs):					
FHP	[1].86	[1].94	[1].95	[1].93	.07
LWT		[1].94	[1].93	[1].94	[1].53
Lean			[1]1.00	[1].99	.23
Water				[1].99	.20
Protein					.24
24 weeks (28 pigs):					
FHP	[1].91	[1].95	[1].96	[1].90	−.16
LWT		[1].92	[1].91	[1].89	−.16
Lean			[1]1.00	[1].98	−.25
Water				[1].98	−.25
Protein					−.26

[1]Probability that r = 0 less than 5 percent.

Table 2.—Regression equations for predicting fasting heat production (Kcal/day) from liveweight (LWT) and weights of body lean and fat, by age group

Component of body weight	Equation	(R^2)[1]
(lb)	**10 weeks**	
Liveweight:		
L[2]	246 + 24.9 LWT	0.52
N[2]	$72.9\ LWT^{0.77}$	.52
Lean:		
L	238 + 29.9 Lean	.58
N	$81.0\ Lean^{0.78}$	.58
	17 weeks	
Liveweight:		
L	278 + 15.0 LWT	.74
N	$33.2\ LWT^{0.87}$	.73
Lean and fat:		
L	447 + 21.3 Lean − 9.5 Fat	.91
N	$64.8\ Lean^{0.80}$ − 8.6 Fat	.91
	24 weeks	
Liveweight:		
L	−566 + 15.4 LWT	.82
N	$4.21\ LWT^{1.21}$	.82
Lean:		
L	364 + 17.2 Lean	.91
N	$44.3\ Lean^{0.84}$	.91

[1]1 − R^2 = fraction of variance in FHP due to deviations from predicted values.
[2]L = best linear regression, N = best nonlinear regression.

Growth of Fetal Pig Muscle Cells in Culture

LeRoy L. Richer[1]

Introduction

Although considerable effort has been expended to identify genetic and chemical factors that promote muscle growth in pigs, the regulation of muscle growth is still poorly understood. A faster and more direct method for studying muscle development would greatly aid these efforts. Growing muscle cells in culture may provide such a new bioassay system. By selectively growing muscle cells in culture, we can observe the direct action of hormones, chemical growth promotants, and serum factors and quantitatively measure muscle growth in response to treatment with these factors. If the cultured muscle cells grow in a normal (that is, physiological) manner, then we can expect that any stimulation by these factors observed in culture is at least qualitatively the same as occurs in the whole animal.

Based on this reasoning, muscle cells at an early stage of development were collected from fetal pigs, and conditions were established for growing these cells in culture. Starting cultures of muscle cells at the single cell stage has proven to be the most successful approach for cell culture, and fetal muscle tissue is an abundant source of such muscle cells. Furthermore, studies by other researchers have demonstrated that muscle cells grown in culture using this technique exhibit the same developmental patterns as muscle cells in whole animals.

An additional advantage of this method is that, by starting at the earliest possible stage of muscle development, the cultured muscle cells grow in an approximately synchronous manner. Thus, cells at discrete stages of development can be treated with suspected growth factors. Using this approach, growth factors can be evaluated as stimulators of cell proliferation (increase in the synthesis of muscle proteins, or hypertrophy), depending on the developmental stage of the cells when treated.

The objectives of these studies were (1) to develop and use muscle cell cultures as a bioassay to evaluate protein hormones and anabolic agents as stimulators of muscle growth, (2) to evaluate the potential of serum collected from pigs with drastically different growth characteristics for stimulating muscle growth in culture, and (3) to develop methods for quantitatively measuring rates of muscle protein synthesis and degradation for muscle cells at various stages of development in culture.

Procedure

For all experiments reported here, muscle cells at the single cell stage (presumptive myoblasts) were isolated from the hind limbs of fetal pigs obtained surgically from white crossbred gilts and sows at 50- to 60-days gestation. Sterile conditions were maintained at all times during the isolation, washing, and preparation of muscle cells for culturing. A constant number of muscle cells were placed in a culture flask in culture medium containing fetal calf serum. After 24 h, culture flasks with equivalent densities of attached cells and similar cell characteristics, as determined by counting and observation under a microscope, were grouped for experiments. Culture medium and unattached cells were removed and fresh medium, supplemented with 2-percent horse serum or test serum (as described below), was added. With appropriate replenishment of culture medium, the muscle cells proliferate and develop into mature, multinucleated muscle cells (myotubes).

Figure 1 shows cultured muscle cells at the different stages of development referred to in this report. Treatment of cultured muscle cells began either after 24 h of culturing or after 2, 4, or 6 days of culturing, as described below.

Experiment 1. Muscle cells were collected and cultured as described above. For these studies, culture medium was replaced at 24 h and, in place of horse serum, suspected growth factors were added to the medium as serum substitutes. Growth factors used singly and in combinations in these studies included growth hormone, insulin, fetuin, transferrin, and fibronectin. Muscle cell growth in the presence of growth factors was monitored by measuring the incorporation of appropriate radioisotope-labeled components added to cultures 12 h after adding the growth factors. The muscle cells were then cultured an additional 24 h before harvesting and assaying the amount of radioactive label incorporated into DNA, RNA, and protein fractions.

Experiment 2. The muscle cell culture system was also used as a bioassay to screen serum collected from pigs at various stages of development and from pigs genetically selected for lean and obese growth traits. Test serum was used in place of horse serum in the procedure described above. Muscle cell growth in the presence of the test serum was again measured by adding appropriate radioisotope-labeled components to cultures 12 h after the start of the serum treatments and harvesting and assaying cells 24 h later.

Experiment 3. Muscle cells were grown in culture to two distinct developmental stages (Fig. 1). To measure cell proliferation and protein synthesis rates for muscle cells at the early developmental stage, we added appropriate radioactive labels to cultures immediately following the 24-h medium change. Culture flasks were harvested at 3, 6, 24, and 48 h after adding the radioactive components, and the muscle cells were assayed for the amount of radioactive label incorporated into cell material.

Muscle cells at a later stage of development were used to determine rates of growth in culture. For these studies, cells were cultured for 6 days. After this time, muscle cells were developing into the mature (myotube) stage. To determine the rates of muscle protein synthesis and degradation (turnover) occurring in cells at this stage, radioisotope-labeled amino acids were added to the muscle cultures, and groups of culture flasks were harvested and assayed 3, 6, and 24 h later. After 24 h, the culture medium in the remaining flasks was changed, and this time radioisotope-labeled amino acids were added only to some of the remaining cultures. Cultures with fresh radioisotope label and cultures without the fresh label were each harvested and assayed 27, 30, and 48 h after the initial addition of radioisotope-labeled amino acids. Those cultures that received fresh radioactive amino acids at the 24 h medium change were used to measure rates of muscle protein synthesis. Those cultures that did not receive fresh radioactive amino acids were used to measure the rate of protein degradation as monitored by assaying the release of radioactive amino acid from muscle protein.

Results

Experiment 1. Insulin has been reported as a metabolic stimulator of a number of cell types. As shown in Figures 2a and 2b, 10 μg/ml insulin alone in serum-free culture medium performs as a suitable substitute for serum. Other potential growth factors, such as fetuin and trans-

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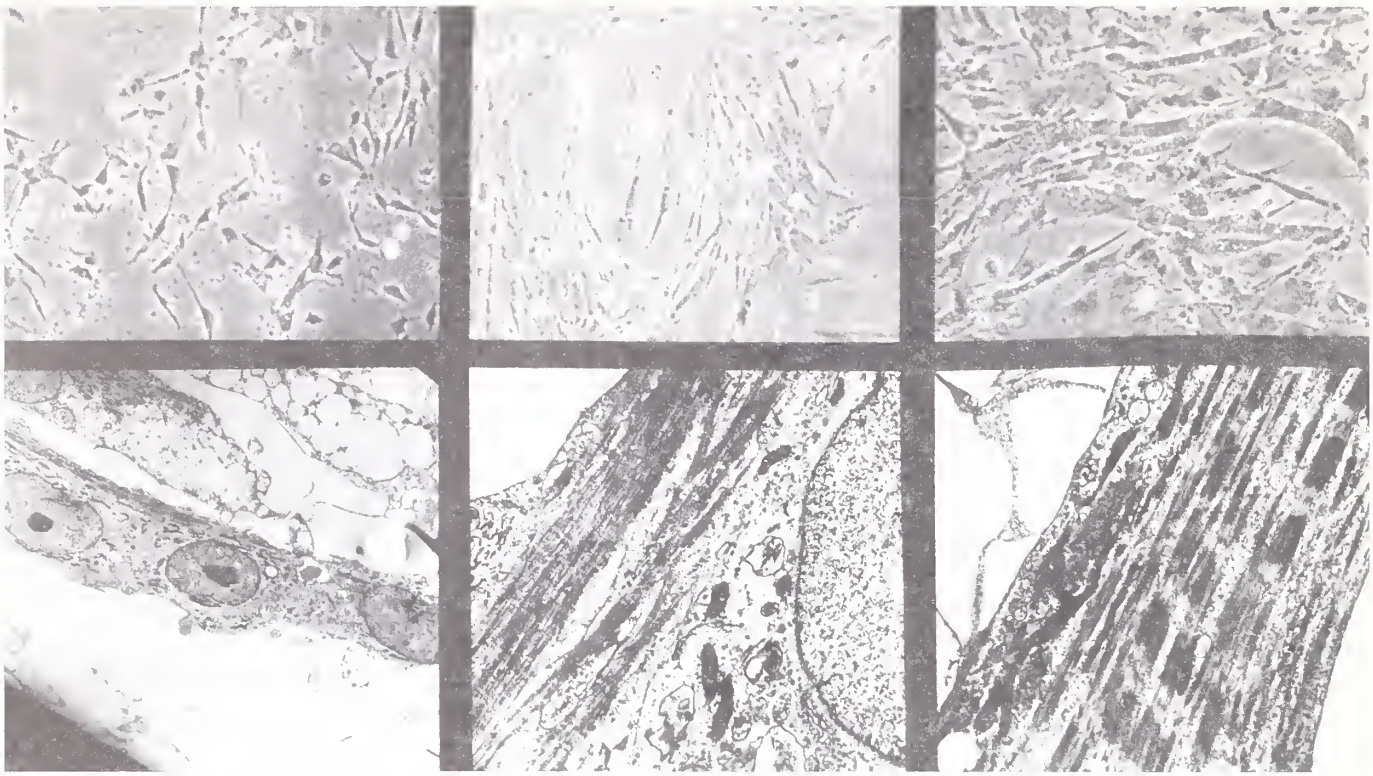

Figure 1—Top row: l to r, Fetal pig muscle cells after 24 h, 3 to 4 days, 6 to 8 days. Bottom row: Mature muscle cells; left, multinucleated cell; center, increased magnification showing subcellular structure; right, high magnification showing increased myofibril development.

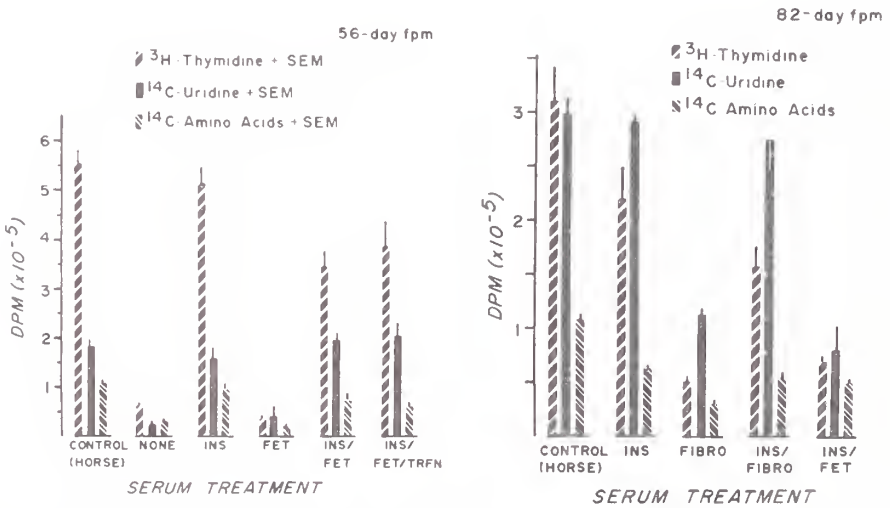

Figure 2—Growth factors as potential substitutes for serum in cultures of fetal pig muscle cells.

ferrin (Fig. 2a), apparently do not sustain muscle cell growth in culture. Likewise, fibronectin (Fig. 2b), and combinations of these potential growth factors with insulin, do not promote muscle cell growth as well as insulin alone.

Insulin and growth hormone were administered to mature muscle cell (myotube) cultures, and the cellular uptake of the amino acid analogue, aminoisobutyric acid (AIB), was measured (Fig. 3). No apparent stimulation of metabolic activity was observed 2 h after administering the two hormones; however, 24 h after hormone administration, growth hormone dramatically stimulated AIB uptake. This apparent stimulation of amino acid uptake was not observed in early development of muscle cells (myoblasts), and subsequent studies measuring amino acid incorporation into protein in both myoblast and myotube cultures did not indicate any stimulation by growth hormone. These results suggest that growth hormone is performing an insulin-like function in assisting transport of amino acid-like materials into cells while not actually stimulating protein synthesis.

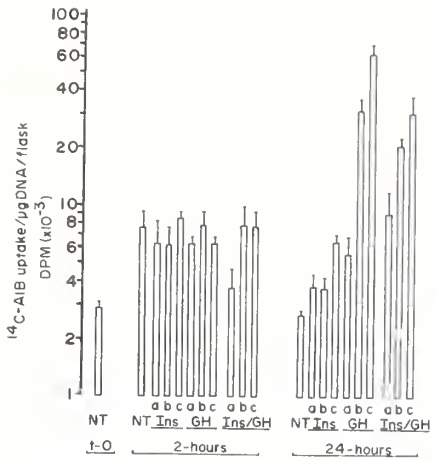

Figure 3—Insulin and growth hormone stimulation of cell metabolism in cultured myotubes.

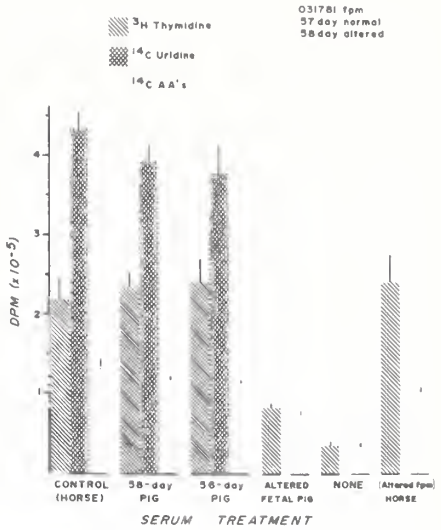

Figure 4—Serum-borne factors affecting muscle cell growth in culture.

Experiment 2. Serum was collected from pigs at several developmental stages and assayed for growth factors, which directly stimulate muscle cell growth. Serum from fetal pigs, 56-day-old rapidly growing pigs, and mature, market weight pigs all demonstrated equivalent muscle-growth-stimulating potential when compared to control muscle cell cultures grown in fetal calf serum or horse serum supplemented medium. Only three sources of pig serum with different muscle-growth-stimulating potential were found. These were fetal pigs that had been mechanically decapitated at 40-days gestation and surgically removed from the gravid uterus at 56-days gestation (Fig. 4), and serum from lean and obese lines of pigs maintained at MARC (Fig. 5). The results obtained, using serum from lean and obese pigs, are presented together with results reported by Michigan State University researchers using serum from conventional breed-type and Ossabaw pigs (an obese wild breed of pig found on the Ossabaw Island off the coast of Georgia) in a similar experimental design. In the studies conducted at MARC, radioisotope-labeled amino acid incorporation into muscle proteins was also measured and compared to results obtained using serum from conventional breeds of pigs. Protein synthesis activity was dramatically higher in muscle cell cultures supplemented with serum collected from lean and obese pigs at three different stages of development.

Experiment 3. Figure 6 summarizes the observed accumulation of ^{3}H-

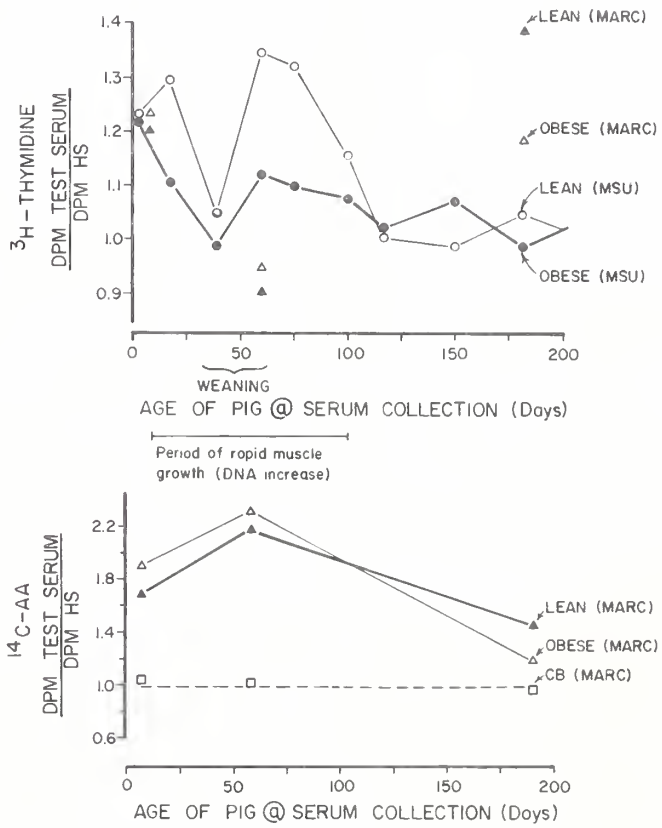

Figure 5—Effect of serum from lean and obese pigs on the growth of fetal muscle cells in culture.

thymidine into DNA and ^{14}C-amino acids into protein in muscle cells at an early (myoblast) stage of development. The rate of incorporation of radioisotope label into DNA appeared to decline 24 and 48 h after adding the ^{3}H-thymidine. This corresponds to 4 to 6 days in culture when, as shown in Figure 1, the muscle cells are reaching a mature (myotube) stage of development, and DNA synthesis (cell proliferation) would be expected to slow down. The rate of accumulation of ^{14}C-amino acids into muscle protein observed in the muscle cultures at the myoblast stage did not appear to differ from rates observed in mature muscle cell cultures.

Rates of radioisotope-labeled amino acid accumulation and release from cultured muscle cells at the myotube stage are indicated in Figure 7. The rate of accumulation of ^{3}H-leucine amino acid into muscle proteins may be obtained from the slope of the line for ^{3}H-leucine at 0-24 h. The rate of release of ^{3}H-leucine, the degradation rate for muscle proteins, may be obtained from the slope of the ^{3}H-leucine line from 27 to 48 h. Since the rate of accumulation is given by the difference of the synthesis rate and degradation rate, all the necessary information is available for calculating muscle protein synthesis rates in these studies. The simultaneous measurement of the rate of accumulation of the ^{14}C-leucine line in Figure 7 demonstrated that the rate of muscle protein synthesis activity did not change during the course of these measurements.

A major result of these studies is the demonstration that muscle cell cultures may be used as a bioassay system to identify growth factors that act directly on muscle cells. Employing rate-measuring assays, such as those described in experiment 3, will allow quantitative comparisons of the degree of stimulation produced by these growth factors.

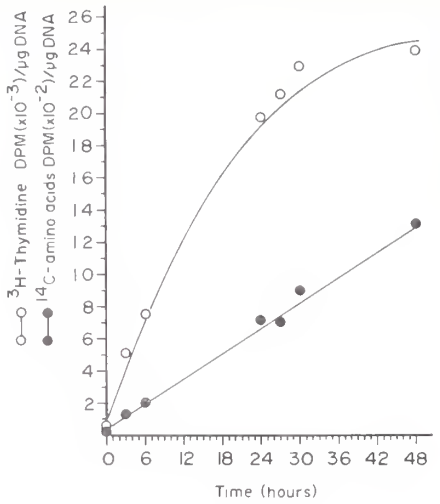

Figure 6—Time course of DNA and protein synthesis activity in myoblast cultures.

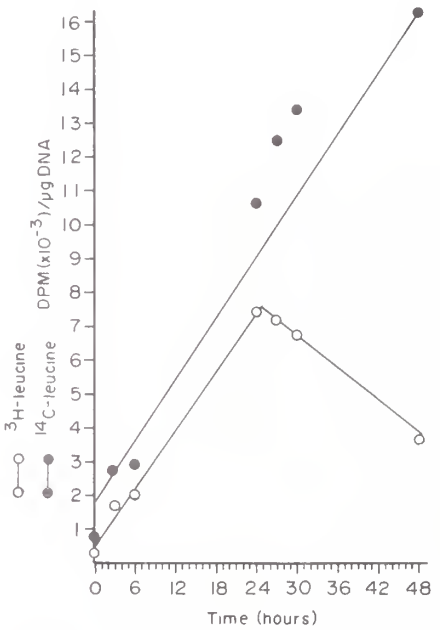

Figure 7—Protein accumulation/turnover rates in major muscle (myotube) cultures.

Survival of Genetically Obese and Lean Swine: Cross-Fostering Experiments

Harry J. Mersmann, Ronald N. Lindvall, Wilson G. Pond, Roger T. Stone, and Jong-Tseng Yen[1]

Introduction

Swine of both the Duroc and Yorkshire breeds were selected for thick and thin backfat for many generations. Although these pigs were not selected for any other growth or reproductive traits, during the many generations of selection other traits may have been selected inadvertently or they may result from the obese state. There is a variation in survival to 21 days of age between lean and obese pigs; the obese lines both had about 89-percent survival, whereas the lean lines had about 78-percent survival or about one pig less/litter. The purpose of this study was to examine factors that might contribute to the greater survival of obese than lean pigs. Cross-fostering was utilized to assess maternal influences.

Procedure

The obese and lean animals used in this study were from *inter se* matings of crossbreds produced by within-line matings of purebred Duroc and Yorkshire animals selected for either maximal or minimal backfat thickness. This was the second pregnancy for all sows. An obese and lean dam were paired (parturition within 24 h). Six pigs were retained within each litter; three of the six pigs were cross-fostered to the dam of the opposite genetic line, and the other three were maintained on the natural mother. The number of live-born piglets was obtained within 12 h of parturition.

The piglets were weighed at birth (within 12 h) and weekly for 4 weeks. Blood samples were obtained by puncture of the anterior *vena cava* (heparin as anticoagulant) at birth and at week 4. Blood was analyzed for hemoglobin, hematocrit, plasma total protein, and plasma albumin. Albumin from prenursing pig plasma was determined also by radial immunodiffusion using an antibody produced against purified porcine serum albumin.

Milk samples were obtained at birth (before nursing and weekly thereafter). Samples were obtained after intramuscular oxytocin injection and were randomly obtained from the udder sections. Milk samples were analyzed for dry matter, total lipid, ash, and for calcium, copper, manganese, magnesium, iron, and zinc absorption. Whole milk samples were analyzed for total protein.

Results

Examination of records kept on obese and lean line reproductive traits at this laboratory since 1978 indicated more total- and live-born pigs and heavier birth weights in the lean than obese lines (Table 1). The latter observation is unexpected since generally larger litters yield smaller pigs at birth than smaller litters. The lower birth weight of the obese pigs (smaller litters) may be a reflection of the previously observed smaller size and weight of internal organs in obese than lean pigs if that smaller size extends to the reproductive tract and its circulatory perfusion or both. In spite of the greater birth weight of the lean than obese pigs, there was greater survival to weaning at 4 weeks in the obese than lean lines; over the 5 years, 90 percent in the obese line survived, as compared with 75 percent in the lean strains. In the current experiment, survival was not a pertinent variable because of the low and fixed size of the litters in the cross-fostering design.

The obese pigs weighed less than the lean pigs at birth (Table 2). Pigs raised on the obese sows, regardless of genetic background, weighed less at week 1 to 4 than those raised on the lean sows (table 2). Obese pigs on lean sows weighed the same as lean pigs at week 1 to 4 in spite of lower birth weights; obese pigs on obese sows weighed less than lean pigs (table 2). The day 0 difference in obese and lean piglet weight had a significant correlation to weight at week 1 and 4; the adjusted weight data presumably indicates postpartum effects and yielded different effects than the unadjusted data. The obese pigs were heavier than the lean, indicating greater gain. The pigs, regardless of genetic background, raised on obese sows were lighter than those raised on lean sows. At week 1 to 4, obese pigs raised on obese sows weighed the same as lean pigs raised on obese sows, indicating equal gain; obese pigs weighed more than lean pigs when raised on lean sows, indicating greater gain (not the same as in unadjusted data).

Lean pigs had lower hemoglobin, hematocrit, total plasma protein, and plasma albumin than the obese pigs at birth. The differences between obese and lean pigs were rectified by 4 weeks of age although albumin remained statistically lower in lean than obese pigs. There were minor but statistical differences in hemoglobin and hematocrit at birth between pigs assigned to lean and obese sows. At week 4, plasma protein was statistically greater in pigs on obese than lean sows; the importance of these minor variations is unknown but probably biologically not relevant.

Analysis of the milk (Table 3) indicated greater dry matter and lipid content at birth and through week 2 in the obese than lean sows. Ash and mineral content were similar in the two lines. There were no differences in the total milk protein or the whey protein content between the two lines at any age. The whey protein fractions did not differ between the two lines at any age.

In summary, piglets raised on lean sows, regardless of genetic origin, weighed more at weeks 1 to 4. This is contrary to the expected result since survival is less when lean sows raise lean pigs (Table 1), and the milk analysis (Table 3) indicated greater dry matter and lipid content in milk from obese than lean sows. We have not measured milk yield; one might speculate that yield was greater in lean than obese sows because of the greater weight gains in the pigs raised on the lean sows. The greater lipid content of colostrum and milk from obese than lean sows may provide critical nutrients or energy sources at the early stages of postpartum life and thus dictate the increased survival of obese piglets when raised on obese sows. This is similar to the increased survival observed by feeding fat to sows during late gestation and early lactation to increase the energy content of milk. The slightly greater hemoglobin, hematocrit, plasma protein, and albumin in obese than in lean pigs may also reflect a more mature physiological status of the obese than lean piglets at birth. Survival does not appear to be a reflection of milk protein content in general or of the individual whey fractions. We have not, of course, evaluated all the possible differences in lean and obese pigs at birth or during the suckling period, nor have we attempted to monitor mothering ability or piglet behavioral patterns in the two groups of sows or pigs.

[1]Mersmann is a research chemist, Meats Unit; Lindvall is the swine operations manager; Pond is the research leader, Nutrition Unit; Stone is a research physiologist, Reproduction Unit; and Yen is a research animal scientist, Nutrition Unit, MARC.

Table 1.—Reproductive traits of obese and lean pigs[1]

Year	No. litters	Gestation length	Total born	Live born	No. weaned[2]	Birth wt	Weaning wt
						(lb)	
Obese:							
1978	17	112.6 ± 0.2	8.2 ± 0.5	7.8 ± 0.5	7.1 ± 0.4	2.1 ± 0.1	11.2 ± 0.4
1979	18	113.2 ± .2	9.5 ± .6	8.4 ± .5	7.9 ± .5	2.0 ± .1	10.1 ± .4
1980	23	113.0 ± .3	7.8 ± .7	7.2 ± .6	6.8 ± .4	2.2 ± .1	11.7 ± .4
1981	18	113.5 ± .4	7.3 ± .5	6.8 ± .5	6.0 ± .6	2.1 ± .1	10.1 ± .4
1982	16	113.1 ± .3	7.3 ± .6	6.9 ± .6	6.5 ± .6	2.1 ± .1	10.1 ± .7
All years	92	113.1 ± .2	8.0 ± .4	7.4 ± .3	6.9 ± .3	2.1 ± .04	10.6 ± .4
Lean:							
1978	13	114.7 ± .4	9.8 ± 1.0	9.1 ± .9	7.2 ± 1.0	2.8 ± .1	10.6 ± .7
1979	13	114.8 ± .6	10.6 ± .6	9.4 ± .8	7.2 ± 1.0	2.6 ± .1	12.1 ± .4
1980	14	114.8 ± .8	10.6 ± .8	8.9 ± .9	7.4 ± 1.1	3.0 ± .1	12.6 ± .9
1981	19	115.5 ± .5	10.1 ± .6	9.3 ± .6	6.4 ± .5	2.6 ± .1	10.8 ± 1.1
1982	17	115.4 ± .3	9.3 ± .8	8.2 ± .7	5.6 ± .9	2.6 ± .1	11.0 ± 1.1
All years	76	115.0 ± .2	10.1 ± .3	9.0 ± .2	6.8 ± .3	2.7 ± .08	11.5 ± .4

[1]Data indicated as mean ± SE.
[2]Number weaned as percentage of number live born; obese = 93, lean = 76.

Table 2.—Piglet weights (mean ± SE)

Item	Obese sow[1]		Lean sow[1]		Combined pigs				Sig.[4]
	Obese pigs	Lean pigs	Obese pigs	Lean pigs	Obese sow[2]	Lean sow[2]	Obese pigs[3]	Lean pigs[3]	
Weight, lb									
Day 0					2.4	2.4	2.2	2.9	P
Week 1	3.5	4.0	4.2	4.4	3.7	4.2	3.7	7.9	S,P (P<0.1)
2	5.1	6.0	6.4	6.6	5.5	6.4	5.7	6.2	S
3	7.1	8.2	8.6	8.8	7.5	8.8	7.9	8.6	S
4	9.0	10.4	11.0	11.2	9.5	11.2	9.9	10.8	S
Adjusted weight, lb[5]									
Week 1	4.0	3.5	4.6	3.7	3.7	7.9	7.9	3.7	S,P, wto,
2	5.7	5.5	7.1	5.7	5.7	6.4	6.4	5.7	S,P, wto, SxP
3	7.9	7.5	9.5	7.7	7.7	8.6	8.6	7.7	S,P, wto, SxP (P<0.1)
4	9.9	9.7	11.9	9.9	9.7	11.0	10.8	9.9	S,P, (P = 0.11), wto, SxP (P<0.1)

[1]n = 17 obese pigs, obese sow; 14 lean pigs, obese sow; 16 obese pigs, lean sow, 16 lean pigs, lean sow.
[2]n = 31 pigs on obese and 32 pigs on lean sows
[3]n = 33 obese pigs and 30 lean pigs.
[4]Significance indicated at (P< 0.05) unless otherwise indicated. S = effect due to breed of sow, P = effect due to breed of donor pigs.
[5]Data adjusted for significant (P< 0.05) day 0 covariate.

Table 3.—Milk analyses

Item	Dry matter	Lipid	Total protein	Whey protein
Prenurse:	(g/100g)		(mg/ml)	
Obese	27.4 ± 1.0	40.8 ± 14.1	[1]18.9 ± 2.0	[1]12.7 ± 1.8
Lean	[3]24.6 ± 1.0	[3]14.2 ± 2.0	19.2 ± 1.0	13.8 ± 1.2
Week 1:				
Obese	21.5 ± .7	62.0 ± 5.9	5.6 ± .3	2.0 ± .2
Lean	[1 2]18.6 ± .5	48.0 ± 3.8	[1]5.3 ± .3	[1]2.0 ± .2
Week 2:				
Obese	19.7 ± .6	[1]51.0 ± 2.9	4.5 ± .5	1.3 ± .2
Lean	[3]18.1 ± .4	[3]42.3 ± 5.2	3.7 ± .8	1.5 ± .2
Week 3:				
Obese	20.3 ± .6	53.0 ± 7.4	5.0 ± .5	1.4 ± .1
Lean	19.1 ± .4	47.6 ± 5.3	4.4 ± .3	1.4 ± .2
Week 4:				
Obese	20.7 ± 1.2	60.8 ± 7.5	5.7 ± .4	1.5 ± .2
Lean	19.4 ± 2.2	54.8 ± 16.3	4.6 ± .9	1.6 ± .1

[1]n = 5.
[2]Data indicated as mean ± SE, P<0 05, n = 6 unless otherwise indicated
[3]Data indicated as mean ± SE, P<0.1, n = 6 unless otherwise indicated.

Use of Carbohydrate and Fat as an Energy Source by Obese and Lean Swine

Harry J. Mersmann, Jenell A. Dague, Wilson G. Pond, and Jong-Tseng Yen[1]

Introduction

Genetically obese and lean swine may be useful models for adipose tissue deposition in growing contemporary pigs or as a model for obesity. Swine selected only for thick or thin backfat for about 18 generations are very different in body composition even at young ages.

The variety of nutritional experiments with genetically lean and obese pigs has not addressed the possibility that obese pigs utilize dietary carbohydrate or fat sources differently than do lean pigs. Consequently, this study was designed to ascertain the effect of the source of dietary energy (fat or carbohydrate) on growth and body composition variables, in genetically obese and lean pigs fed a high- or low-fat diet, at isoenergetic and isonitrogenous levels.

Procedure

Obese and lean animals were females and males from *inter se* matings of crossbreds produced by within-line matings of purebred Duroc and Yorkshire pigs selected for either maximal or minimal backfat thickness. Six pigs, three female and three male, per genetic strain (obese or lean), were selected at about 55-lb body weight and were fed either a low- or a high-fat diet. The low-fat diet was fed to approach *ad libitum* levels. One pig of a genetic strain was fed the low-fat diet and was paired with another pig of the same genetic strain fed an isoenergetic-isonitrogenous amount of the high-fat diet. Weights were obtained weekly and are summarized for about 7-week periods.

Carcass measurements were on cold carcasses that were fabricated into six rough cuts: loin, ham, butt, picnic, belly, and trim. The loin, ham, butt, and picnic were trimmed of all subcutaneous fat and finally were deboned. Selected data are presented for weights of these cuts at several stages of fabrication.

Results

Obese pigs gained essentially the same weight when pair-fed a high-fat diet at isoenergetic and isonitrogenous levels to a low-fat diet (Table 1). The high-fat diet was fed at about 86 percent (weight basis) of the low-fat diet throughout the study and, consequently, the feed/gain ratio was less although the calculated energy/gain ratio was the same for both diets over the entire study. Similar results were obtained with lean animals (Table 1); however, the high-fat diet was fed at about 88 percent (weight basis) of the low-fat diet, slightly greater than desired. This overfeeding probably led to the greater weight of lean pigs fed the high-fat compared to the low-fat diet. Lean pigs grew slightly faster and were more efficient (lower feed/gain ratio and energy/gain ratio) than obese pigs when fed a given diet.

Obese pigs were considerably fatter than lean pigs at several body positions at the initiation of the experiment (about 10 weeks of age) and at all times thereafter. The longissimus muscle area was greater in the 55 lb obese than lean pigs; later this muscle area was about the same in the two genetic strains and, at the termination of the study, the longissimus of the lean pigs had a greater area than that of the obese pigs (Table 2).

The obese carcass was shorter, fatter, less muscular, and with less skeletal mass than the lean carcass at the termination of the study (Table 2). The carcass weights were similar in the two groups even though the obese pigs weighed less at slaughter than the lean. Conformation was different in the carcasses of the obese and lean pigs; the rough loin and butt weighed about the same in the two strains, but there was a difference in the weight of the rough ham and picnic between the strains. Generally, there was less muscle mass in obese than lean pigs as indicated by the trimmed cuts (or by the trimmed, deboned cuts; data not indicated).

Although the lean pigs were more energetically efficient (possibly because lean pigs have greater gut length and mass) than the obese pigs (Table 1), the growth and energetic efficiency was similar in pigs within a given strain fed the high- or low-fat diet. Pigs fed the low-fat diet, however, were thinner than pigs of the same strain fed an isoenergetic-isonitrogenous amount of the high-fat diet. This was evident at several body locations (Table 2) and could be detected ultrasonically after 14 weeks on the diets, especially in the forequarters.

[1]Mersmann is a research chemist, Meats Unit; Dague is an agricultural research technician, Swine Unit; Pond is the research leader, and Yen is a research animal scientist, Nutrition Unit, MARC.

Table 1.—Animal growth and efficiency[1]

Item	Breed: / Diet:	Obese Low-fat	Obese High-fat	Lean Low-fat	Lean High-fat
Week 0:					
Weight	lb	55.0	55.0	53.0	53.0
Week 7:					
Weight	lb	90.0	90.0	95.0	99.0
Feed, (wk 0 to 7)	lb	104.0	88.0	106.0	95.0
Feed/gain		6.6	5.5	5.5	4.4
Week 14:					
Weight	lb	148.0	150.0	157.0	163.0
Feed, (wk 0 to 14)	lb	302.0	258.0	302.0	260.0
Feed/gain		7.3	6.0	6.4	5.3
Week 20:					
Weight	lb	181.0	185.0	192.0	207.0
Gain	lb	126.0	130.0	139.0	154.0
Feed, (wk 0 to 20)	lb	459.0	395.0	445.0	392.0
Feed/gain		7.9	6.6	7.1	5.5

[1]Data indicated as mean ± SE

Table 2.—Body composition[1]

Item	Breed: / Diet:	Obese Low-fat	Obese High-fat	Lean Low-fat	Lean High-fat	Sig[2]
Cold weight	lb	119.0	126.0	117.0	135.0	
Length	in	27	26	31	31	G
Avg. backfat	in	2.0	2.2	.8	1.0	G,D
Longissimus area	in^2	3.7	3.3	4.5	4.2	G
Ham, lb:						
Rough		13.0	13.5	14.3	15.9	G,D ($P<0.1$)
Trimmed		8.8	8.8	12.1	13.5	G
Loin, lb:						
Rough		16.5	18.5	15.4	18.1	D
Trimmed		8.4	8.8	12.6	13.4	G
Butt, lb:						
Rough		7.9	8.6	8.6	9.0	
Trimmed		4.6	4.9	6.8	7.3	G
Picnic, lb:						
Rough		6.8	6.8	8.2	8.8	G
Trimmed		5.1	4.9	6.8	7.3	G
Belly	lb	10.8	11.2	7.3	8.8	G,D ($P=0.11$)
Miscellaneous	lb	3.3	3.5	4.6	5.1	G,D ($P<0.1$)
Fat	lb	17.2	20.1	8.2	11.2	G,D
Bone	lb	4.4	4.2	6.2	6.8	G
Yields, percent:						
Lean cuts[3]		46	44	65	63	G,D ($P<0.1$)
Debone lean/side[4]		39	35	54	52	G,D ($P>0.1$)
Debone lean/liveweight		25	23	33	33	G

[1]Data indicated as least squares mean values with the pooled SE.
[2]Statistical significance at $P<0.05$ unless indicated. G = genetic strain effects; D = diet effects. There were no significant sex or interaction effects.
[3]Trimmed ham + loin + butt + picnic weight/side weight.
[4]Deboned ham + loin + butt + picnic weight/side weight.

Utility of Ultrasonic Determination of Body Composition in Growing Swine

Harry J. Mersmann[1]

Introduction

Many studies of animal growth could be improved if muscle and fat deposition were assessed during the experiment rather than only at the termination, which usually culminates in slaughter. Ultrasonic methods provide a nondestructive means of repeatedly measuring fat deposition and muscle growth in the same animal. In this study, the utility of ultrasonic measurements in providing information about body composition of growing swine was assessed. Various ultrasonic measurements of backfat depth and longissimus muscle (loin eye) area were obtained on live swine, and these measurements were compared to traditional measurements obtained on the carcass from the same animal. The capability to detect short-term changes in backfat depth and longissimus area as well as changes in individual backfat layers with ultrasonic techniques was explored.

Procedure

The animals were suspended on their bellies in a special tubular steel crate and ultrasonically scanned[2] with the velocity of the instrument set at 12.8 microsec/in as recommended by the manufacturer. After the animal was suspended, the live length was measured from the base of the skull to the base of the tail, and one-fifth, one-half, and three-fourths of this length were marked on the animal's left side with a paint stick. All ultrasonic measurements were made on the right side perpendicular to the cephalic-caudal axis. Light mineral oil was used as a conducting medium between the skin and the transducer. Two full scans were obtained at one-half body length, and a half scan was obtained at one-fifth and three-fourths body length unless complications necessitated additional scans, such as animal movement during the scan. The photographs (half size in both axes) were traced onto acetate paper, and the fat depth directly over the vertebral column at one-fifth, one-half, and three-fourths body length and 2 in lateral to the vertebral column at one-fifth, one-half, and three-fourths body length were indicated. At one-half body length, the longissimus dorsi muscle area was traced from the better of the two pictures; the second picture was used for clarification. Finally, at one-half body length, the fat depth perpendicular to the skin and at three-fourths lateral length of the longissimus muscle was indicated (½-loin). All interpretation of scans, as well as measurement of depths and areas, were performed by a single operator in each experiment.

The animals were slaughtered and carcass length, carcass backfat (at the first rib, last rib, and last lumbar vertebra), carcass longissimus area at the 10th to 11th rib interface, and carcass backfat at three-fourths the lateral length of the longissimus muscle at the 10th to 11th rib (carcass, backfat-loin) were obtained on hanging right half carcasses after 48 h at 38°F.

Results

Marked changes in mean body components were observed by ultrasound as the weight doubled from 88 to 175 lb (Table 1). The longissimus area increased about 80 percent, whereas the extent of backfat growth depended on the specific anatomical location. Over the vertebral column, backfat depth increased about 40, 80, and 55 percent at one-fifth, one-half, and three-fourths body length, respectively. Two inches lateral to the vertebral column, the increases were about 90, 55, and 70 percent at one-fifth, one-half, and three-fourths body length, respectively. Backfat at one-half loin increased about 80 percent during this period. The growth rate for each variable was approximately linear and was calculated for the weight change from 88- to 205-lb body weight (Table 1).

These rates may be deceptive because they are in absolute units; for example, "½-vert. col." and "¾-vert. col." have the same growth rate, but the respective percentage increases over most of the growth period (from 88 to 175 lb) were 80 and 55, respectively. Curvilinear patterns of growth were observed for most variables; consequently, rates were not calculated because of the complex patterns coupled with only three data points.

In further application of sequential monitoring of individual animals, both male and female animals were measured at about 45 lb body weight and again after 5 weeks (Table 2). Body weight increased 140 percent and longissimus area increased about 120 percent. In contrast to the previous experiment with heavier animals (Table 3), the percentage increase in backfat was greater and distributed differently. Over the vertebral column, the increases were about 140, 100, and 170 percent at one-fifth, one-half, and three-fourths body length, respectively, whereas 2 in lateral to the midline, the increases were about 165, 100, and 180 percent at the same body length positions. The increase at one-half loin was about 130 percent. The large increase in all ultrasonic variables yielded readily detectable changes during the 5-week growth period.

In a similar experiment (Table 3), a smaller number of animals were monitored weekly for 5 weeks. Since the increase with time for all variables was linear, growth rates were calculated on this basis (Table 3). For the entire 5-week period, body weight increased about 130 percent and longissimus area about 110 percent. Backfat depth increased over the vertebral column by about 100 percent at one-fifth, one-half, and three-fourths body length, whereas at 2 in lateral, the increases were about 65, 115, and 125 percent at the same body length positions. The increase at one-half loin was about 115 percent.

Caution must be taken in extrapolating detailed patterns of adipose tissue growth from small numbers of animals or from only one experiment. Significant differences in the longissimus muscle area were observed in as little as 2 weeks, whereas only 1 week of growth was needed to detect significant differences in fat depth. In this rapid stage of growth, the ultrasonic technique allowed the recognition of body composition changes over short time periods.

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[1]Mersmann is a research chemist, Meats Unit, MARC.

[2]Scanogram Model 722, Ithaco, Inc., Ithaca, N.Y. 14850.

Table 1.—Ultrasonic variables during growth[1]

Variable[2]	Initial value, mean ± SE	Increase[3]
		(pct)
Liveweight----------lb---	88.0 ± 2.2	95
Live length----------in---	36.0 ± 2.2	26
Longissimus area-----in---	1.8 ± .1	83
Backfat, in:		
1/5-vert. col. ----------	.9 ± .1	41
1/5-5 cm lat. ----------	.5 ± .1	92
1/2-vert. col. ----------	.4 ± .1	80
1/2-5 cm lat. ----------	.4 ± .1	55
1/2-loin----------	.4 ± .1	82
3/4-vert. col. ----------	.6 ± .1	56
3/4-5 cm lat. ----------	.5 ± .1	69

[1]There were 23 Yorkshire pigs (12 females) in the experiment. Each animal was measured sequentially (initially at about 88 lb body weight, 40 days later at an average body weight of 172 lb, and terminally at about a constant weight of 205 lb).

[2]Backfats were measured over the vertebral column (vert. col.) and 2 in lateral to the vertebral column (2 in lat.) at 1/5, 1/2, and 3/4 body length. A seventh fat depth was measured 3/4 the lateral distance over the longissimus muscle at 1/2 body length (1/2-loin). The longissimus area was measured at 1/2 body length.

[3]Percentage increase in the variable from the initial measurement to that 40 days later when the weight essentially doubled.

Table 2.—Fat depth and longissimus area changes during short-term growth of pigs[1]

Variable[2]	Initial, mean	Terminal, mean	Increase[3]
			(pct)
Weight----------lb---	42.0	101.0	142
Longissimus area ---------- in^2---	9.0	2.0	122
Backfat, in:			
1/5-vert. col. ----------	.4	1.1	146
1/5-5 cm lat. ----------	.2	.6	167
1/2-vert. col. ----------	.3	.5	100
1/2-5 cm lat. ----------	ND[2]	.5	
1/2-loin----------	.2	.5	133
3/4-vert. col. ----------	.3	.7	171
3/4-5 cm lat. ----------	.2	.7	183

[1]Pigs (15 male and 15 female) were ultrasonically measured initially and then 5 weeks later. Although there were significant sex effects for some variables, the data were combined for this presentation.

[2]Backfats were measured over the vertebral column (vert. col.) and 2 in lateral to the vertebral column (2 in lat.) at 1/5, 1/2, and 3/4 body length. A seventh fat depth was measured 3/4 the lateral distance over the longissimus muscle at 1/2 body length (1/2-loin). The loin area was measured at 1/2 body length. ND = not determined.

[3]Percentage increase from initial to terminal measurement.

Table 3.—Weekly changes in backfat depth and longissimus area in swine[1]

Variable[2]	Initial, mean	Increase[3]	Detection[4]
		(pct)	(week)
Weight----------lb---	42.0	132	1
Length----------in---	26.5	32	1
Longissimus area---------- in^2---	1.2	110	2
Backfat, in:			
1/5-vert. col.----------	.5	100	1
1/5-5 cm lat.----------	.4	67	1
1/2-vert. col.----------	.3	114	1
1/2-5 cm lat.----------	.2	117	1
1/2-loin ----------	.2	117	1
3/4-vert. col.----------	.4	100	1
3/4-5 cm lat.----------	.3	125	1

[1]Ten pigs were ultrasonically measured initially and then once each week for the next 5 weeks. Mean terminal weight was 97 lb with an SD of 7.

[2]Backfats were measured over the vertebral column (vert. col.) and 2 in lateral to the vertebral column (2 in lat.) at 1/5, 1/2, and 3/4 body length. A seventh fat depth was measured 3/4 the lateral distance over the longissimus muscle at 1/2 body length (1/2-loin). The loin area was measured at 1/2 body length.

[3]Percentage increase from initial to terminal measurement.

[4]Interval (wk) at which significant ($P \leq 0.05$) differences from the initial measurement were detectable by paired t-test.

Plasma Glucose, Insulin, and Lipids during Growth of Genetically Lean and Obese Swine

Harry J. Mersmann, Wilson G. Pond, and Jong-Tseng Yen[1]

Introduction

Pigs may present a useful experimental model for obesity. In most rodent models, and in many humans, obesity is associated with aberrations in carbohydrate and lipid metabolism, producing elevated plasma glucose, insulin, triglyceride, or cholesterol. Similarly, in studies comparing an obese feral line of pigs with contemporary pigs, differences were observed in rate of glucose clearance and in plasma insulin, growth hormone, cholesterol, triglyceride, and lipoprotein concentrations. The present experiments examine the fasting plasma glucose, insulin, triglyceride, and cholesterol levels in genetically obese and lean pigs (derived from Duroc and Yorkshire lines) to establish whether the propensity toward obesity is associated with aberrations in glucose metabolism and circulating lipids.

Procedure

Four female pigs were randomly selected at birth from each of three, four, and three litters (12, 16, and 12 pigs) of the lean, obese, and contemporary groups, respectively. The lean and obese pigs were from *inter se* matings of crossbreds produced by within-line matings of purebred Duroc and Yorkshire breeds selected for high- or low-backfat thickness for 18 generations. Contemporary pigs were from reciprocal crosses of Landrace and Yorkshire purebred animals. Litters of pigs were kept with their dams in an environmentally controlled building until weaning at 4 weeks of age. They were moved to another environmentally controlled building (four or five pigs/pen) at weaning and moved again at about 11 weeks of age. At weaning, each genetic group was reduced to nine pigs; pigs were penned with genetic peers in two replicate pens/genetic group. The postweaning pigs were fed standard corn-soybean meal-type diets *ad libitum*. The protein level of the diet was 18 percent at weaning and was reduced to 16 and 14 percent at about 10 and 16 weeks, respectively, by altering the ratio of corn-to-soybean meal. Body weight of all pigs in the experiment was recorded at birth, weaning (4 weeks), and at 6, 12, 16, and 22 weeks of age.

A blood sample with heparin as anticoagulant was obtained from the anterior *vena cava* of each pig at birth and biweekly thereafter throughout the 22-week experiment, following a 16-h fast (presuckling at birth). Plasma was used for glucose, insulin, triglyceride, and cholesterol determinations. Two pigs from each pen (four/genetic group) were used for an oral glucose tolerance test at weeks 4 and 16. After a 16-h fast, blood was drawn from the *vena cava* at 0 (before) and at 30, 60, 120, and 240 min after an oral glucose load (1.403/lb body weight of a 20g/100ml solution) delivered through a stomach tube.

Results

Although not measured in the present study, similar pigs of the obese and lean strains had average backfat thickness of 2.6 and 0.9 in, respectively, at 210-lb body weight and 0.9 and 0.5 in, respectively, at 55-lb body weight.

Plasma glucose concentration (Fig. 1) was generally similar (no overall breed effects) and normoglycemic in all strains over the entire study; however, it was low at birth in all breeds and increased at 2 weeks of age. Since the nonsuckled newborn pig maintains glucose homeostasis by glycogen mobilization, and the time of sampling for newborn pigs was not rigorously controlled (0 to 12 h), the differences between strains at birth may not be real. Glucose concentration gradually declined with age in all strains. (At 8 weeks of age, the contemporary line had lower concentrations than the lean and obese. This difference in plasma glucose and the elevated glucose in all strains at 12 weeks are inexplicable; however, the latter result was more or less temporally associated with a change in diet and building.)

Plasma insulin concentration (Fig. 2) was lower overall in the lean than in the obese or contemporary pigs. Lower insulin levels in the lean compared to other groups were especially obvious at or greater than 12 weeks of age. The biological importance of the difference in plasma insulin concentration among breeds is unclear, particularly in view of the large coefficient of variation (87.8 pct), the similar glucose tolerance curves in all three breeds (see below) and the similarity in concentrations of other plasma metabolites among breeds. The day 0 values were in concert with the day 0 plasma glucose values. The overall pattern was for insulin to increase with age in all strains. The age x breed interaction was the result of a greater increase in plasma insulin with age in obese compared to contemporary and lean pigs. None of the breeds appeared hyperinsulinemic throughout the study since the greatest mean level was 24 units/ml at any time point for any strain.

Glucose tolerance of four pigs from each genetic group at 4 and 16 weeks of age was similar among genetic groups. Plasma glucose levels were similar at all sampling periods following oral glucose

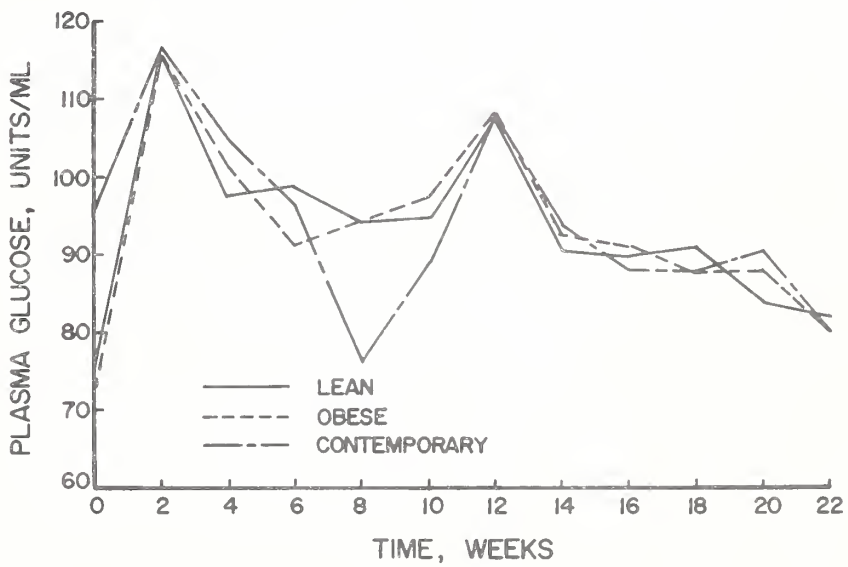

Figure 1—Plasma glucose concentration.

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administration. Expression of glucose tolerance as the area under the curve also indicated similarity among genetic groups in response to an oral glucose load.

Triglyceride concentration was low in plasma in all breeds at all ages. There were no overall breed effects, but there was a gradual decrease in plasma triglyceride with age in all breeds.

Plasma cholesterol was similar between breeds (Fig. 3) over the entire study. The plasma levels were low at birth, rose during suckling, declined markedly at 6 weeks, and rose very gradually thereafter. The elevated plasma cholesterol in suckling pigs probably reflects the high fat and cholesterol content of sows milk. The depressed levels at 6 weeks may represent the change in diet (30 pct of dry matter in sows milk as fat) at weaning (postweaning diet about 4 pct fat). The postweaning plasma cholesterol levels were not elevated in any strain (about 1mg/ml).

Despite vast differences in net body fat accretion between genetically selected obese and lean pigs used in this experiment, there were no obvious variations in the ability to maintain homeostasis of plasma glucose or lipids in obese pigs. Furthermore, the glucose tolerance curves of obese pigs suggest no relationship between the propensity to obesity and peculiarities in glucose metabolism. The obesity observed in these genetically selected pigs may result from increased rates of fatty acid synthesis in adipose tissue coupled with a decrease in the rate of adipose tissue, epinephrine-stimulated lipolysis. Regardless of the mechanism for increased accretion of fat, this population of obese pigs apparently manifests its obesity without additional confounding complications of carbohydrate or lipoprotein metabolism as do many rodent models. Thus, it appears extremely useful as a model to examine the adipose tissue metabolic bases of obesity.

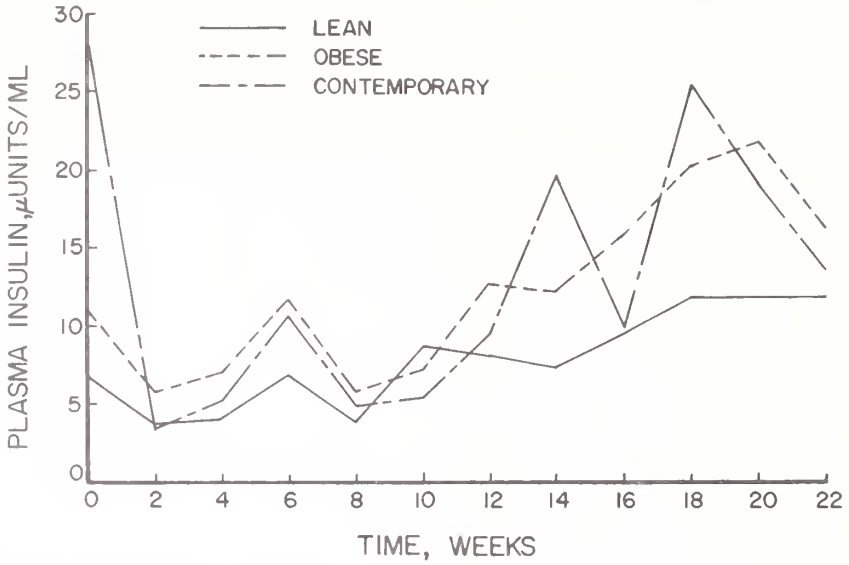

Figure 2—Plasma insulin concentration.

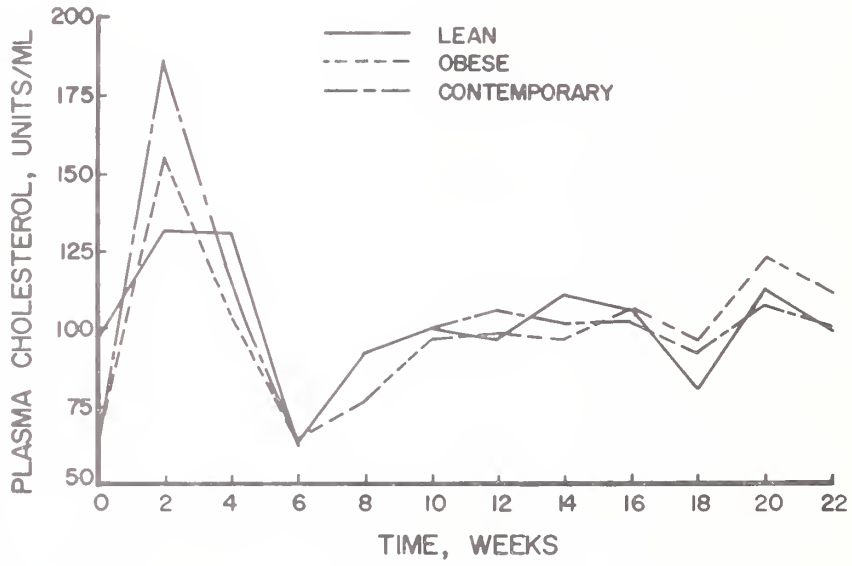

Figure 3—Plasma cholesterol concentration.

Nutritional-Environmental Effects on Nursery-Age Pigs

John A. Nienaber and G. LeRoy Hahn[1]

Introduction

Weaning pigs causes a stress that involves a change of diet, a probable change of environment, and sociological adjustments as a result of mixing litters. Fighting among pigs, although violent, generally subsides within the first day, but other changes require a longer adaptation period and may continue to be stressful. Feeding trials were designed to evaluate interaction effects of environmental temperature and ration energy content on newly weaned pigs. Subsequent studies were conducted to evaluate the importance of water-flow rate and farrowing-house temperature on the performance of animals in the nursery.

Procedure

Trial I. Seventy-two crossbred pigs, farrowed in August, were assigned four pigs/pen to two replicates of nine treatments involving all combinations of three rations (varying in energy content) and three environmental temperatures. Pigs averaging 17.9 lb at an age of 4.3 weeks were fed rations containing 1.30-, 1.44-, or 1.58-Mcal/lb metabolizable energy and 20-percent protein. Environmental temperatures used were 41, 68, and 95°F, which encompass the extremes of conditions expected to be found in a production nursery. During the 7-week feeding trial, feed intake and animal weights were recorded once/week.

Trial II. Seventy-two pigs of similar breeding used in Trial I and averaging 17.9 lb, but farrowed in December and January, were used in Trial II. Treatments used were identical to those of Trial I. Animals were weighed three times/week, and heat production measurements were made four times during the 7-week period. Carcass composition measures were made at the end of the study on two pigs from each pen.

Trial III. Seventy-two crossbred animals, farrowed in December and January and weighing an average of 17.0 lb at 4.2 weeks of age, were selected from two groups farrowed and reared at temperatures of 59° and 81°F. Pigs were assigned to temperatures of 41° or 77° and fed a ration containing 1.30- or 1.58-Mcal/lb metabolizable energy and 20-percent protein. Animals were weighed three times/week, blood samples were collected once/week, and three heat production measurements were made during the 6-week trial.

Trial IV. Forty-eight crossbred animals, farrowed in January and weighing an average 16.1 lb, were assigned to treatments of 41° and 68°F and fed a ration containing 1.44-Mcal/lb metabolizable energy and 18-percent protein. Pens with solid side walls were compared to pens with open mesh walls at the two temperatures. Animals were weighed and fed, and water intakes were measured on weekly intervals. The experiment was conducted for 6 weeks.

Results

Trial I. Experimental results from all feeding trials are contained in Table 1. Growth rate of the nursery-age pigs was unaffected by ration energy content in Trial I. Animals were able to adjust feed intake to maintain growth rate at all three ration treatments as indicated by the increased feed intake with decreased ration energy. Environmental temperature did not affect growth at 41°F, but growth at 95° was 34 percent lower than at 68°. The best feed conversion was obtained at 68° and with the high-energy ration.

Trial II. The results of Trial II indicated that animals were apparently unable to adjust feed intake to maintain growth with the medium- and low-energy rations. As a result, the high-energy ration showed an improved growth rate and feed conversion at all temperatures. The effects of environmental temperature in the second trial were also different from thermal effects of the first experiment; that is, there was a reduced growth rate at 41°F as well as at 95° when comparing growth rate to that of pigs at 68°. Feed intake at 41° and 68° did not differ greatly in the second trial, which also indicated that the animals were unable to adjust to the higher energy demand. Heat production measurements are summarized in Figure 1 and show an increase in heat production with decreasing temperature and increasing body weight. There were also many cases of diarrhea treated during Trial II while only minor untreated cases were seen in the first trial. Three of 72 pigs died in the second trial from viral infections, 2 in the 68°-medium-energy ration treatments and 1 in the 41°-high-energy treatment.

Carcass measurements taken on two pigs from each pen showed that the

Table 1.—Effects of environmental temperature and ration energy content on performance of pigs in the nursery

Trial	Initial wt	No. pigs	ADG	Feed in	Conversion	Length
	(lb)		------- (lb/day)------		(lb/lb)	(days)
Trial I:						
41°F ----------	17.4	24	1.29	2.43	1.91	49
68°F ----------	17.9	24	1.33	2.29	1.81	49
95°F ----------	18.5	24	.88	1.57	1.88	49
Low ----------	17.6	24	1.16	2.31	2.01	49
Medium ----------	18.1	24	1.18	2.09	1.87	49
High ----------	17.9	24	1.16	1.87	1.70	49
Trial II:						
41°F ----------	16.8	24	1.01	2.34	2.38	49
68°F ----------	18.5	24	1.14	2.25	2.00	49
95°F ----------	18.1	24	.77	1.46	1.90	49
Low ----------	18.1	24	.88	2.09	2.35	49
Medium ----------	17.6	24	.89	1.90	2.14	49
High ----------	17.6	24	1.16	2.07	1.80	49
Trial III:						
41°F-Nursery ----	16.8	36	1.05	2.34	2.22	42
77°F-Nursery ----	17.2	36	1.19	2.09	1.75	42
Low ----------	17.0	36	1.09	2.29	2.10	42
High ----------	17.2	36	1.15	2.12	1.85	42
59°F-Farrow -----	17.0	36	1.10	2.09	1.91	42
77°F-Farrow -----	17.0	36	1.14	2.31	2.03	42
Trial IV:						
41°F ----------	15.5	24	1.16	2.91	2.55	49
68°F ----------	16.8	24	1.25	2.67	2.10	49

[1]Nienaber and Hahn are agricultural engineers, Agricultural Engineering Unit, MARC.

pigs at 68°F and on the high-energy diet had 40 percent more fat than the average (10.9 pct) while pigs on the low-energy diets at 41° and 95° were extremely lean (4- to 7-pct fat content).

Trial III. Since Trials I and II were conducted during two different seasons, we felt that farrowing-house conditions may have contributed to the differences measured in performance. When pigs farrowed and reared at 59° or 81°F were weaned at environmental temperatures of 41° and 77°, no difference was seen over the total 6-week period because of the farrowing-house temperature; however, there was a significantly lower growth rate seen in the 59° (farrowing house) group during the first 3 weeks after weaning. The average weight at weaning was higher for the lower farrowing-house temperature, but the intake of creep feed in the farrowing house was approximately 50 percent of that consumed by pigs farrowed at 81°. Apparently, the pigs reared at 81° nursed less, therefore, became better adapted to solid feed (at weaning) than those farrowed at 59°. The difference seen at 3 weeks after weaning, however, was fully recovered by 6 weeks after weaning. Although growth rate tended to decrease with ration energy, differences caused by ration energy contents were not shown to be statistically significant.

Trial IV. Pen wall was shown to have no effects on growth rate of pigs fed at 41° and 68°F; however, pigs grown at 41° did gain less and were less efficient than pigs held at 68°, which was also in agreement with Trial II. Even though feed intake tended to be higher at 41°, pigs were apparently unable to meet their energy needs by increasing feed intake.

Discussion

Results from these four trials, although contradictory in some ways, demonstrate a pattern of performance of animals that is dependent on environmental temperature. It is obvious that 95°F is too warm for 4-week-old weanling pigs as it caused a 33-percent reduction in growth rate in both Trials I and II. This reduction was probably caused by a reduction in feed intake at the high temperature. We felt that the high-energy ration might offset the reduction in feed intake by supplying nutrients at a higher concentration; however, there was no apparent advantage in using the high-energy ration in Trial I. The high-energy ration in Trial II, however, did show increased performance but surprisingly at all three temperatures. This indicated another factor had interacted to affect the pig's ability to adjust feed intake. Since the farrowing-house temperature was probably warmer in Trial I than in Trial II, Trial III was designed to evaluate the effects of farrowing-house temperature on growth in the nursery. The results of the third trial showed no significant effects of farrowing-house temperature on growth in the nursery; however, growth at 41°F was shown to be lower than at 77°. Although there was no statistically significant difference caused by the energy content, the trend in Trial III data was in agreement with Trial II (high-energy ration had greatest growth rate). Growth rate also tended to increase with the higher farrowing-house temperature. Pigs from the warm farrowing house consumed approximately twice as much creep feed in farrowing house as those from the cool farrowing house. After weaning, pigs from the warm farrowing house ate more feed and grew faster during the first 3-week period in the nursery than pigs from the cold farrowing house. The differences, however, diminished by the sixth week of the experiment and were not statistically different at the end of the experiment.

There are several conclusions that can be drawn from this series of experiments on nursery-age pigs:

1. Nursery temperatures of 95°F or higher can be expected to reduce performance of 4-week-old and older pigs even though high-nutrient content rations are given.
2. Pigs farrowed during the cold season may adapt to nursery conditions slower than pigs farrowed during the warm season. Adaptation may be accelerated by maintaining a warm nursery and increasing ration energy content; however, some loss in production may be expected.
3. Pigs farrowed during warm or temperate seasons can be expected to tolerate cooler temperatures and lower energy content rations than pigs farrowed during cold seasons.

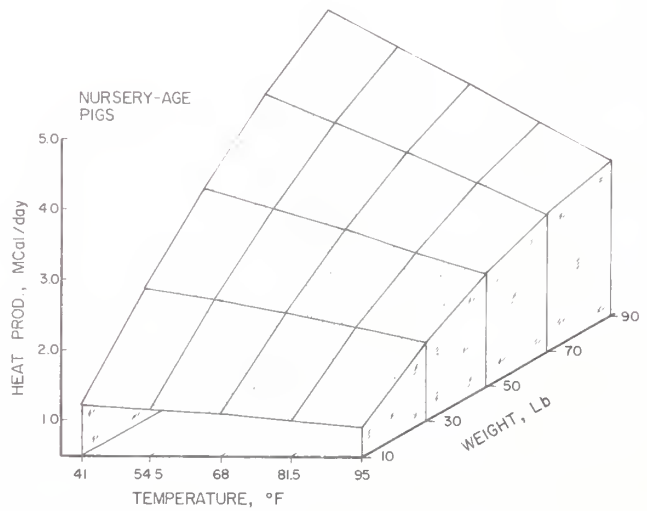

Figure 1—Heat production of nursery-age pigs as affected by environmental temperature and size.

Effect of Water Flow Restriction and Environmental Temperature on Performance of Nursery-Age Pigs

John A. Nienaber and G. LeRoy Hahn[1]

Introduction

Nipple waterers are a widely accepted method of providing an abundant supply of fresh drinking water to livestock. The nipple waterer, however, can become partially plugged and reduce the rate at which water is delivered to the animals. Partial plugging can go undetected because some water may be available when waterers are checked. Measured decrease in water consumption, feed intake, and growth of pigs during a recent experiment was found to be the result of such a restriction. Conversations with nipple waterer manufacturers indicated that water flow rates for optimal production were unknown. One manufacturer indicated that the design flow rate was based on minimizing the water wasted (by observation) by the animal while drinking.

The objectives of this study were to determine the influence of water flow rate on performance of pigs, including any effects that ambient temperature might have on flow rate requirements.

Procedure

Trial I. Commonly available nipple waterers were supplied with water by gravity from individual tanks for each pen. Manufacturer recommendations ranged from 400 to 800 cc/min, depending on the animal weight. The restricted flow rate encountered in the earlier experiment was measured at 100 cc/min; therefore, water flow rates of 100, 600, and 1,100 cc/min were selected to cover the full range of conditions likely to be encountered. Flow rates were varied by use of a blank plate of the type normally used for orifice plates by the manufacturer and drilling the orifice to provide the desired flow rate. Because of the low delivery pressure, the highest flow rate also required some machining of the spindle of the waterer. Flow rates achieved were ± 5 percent of the desired values.

Since water requirements of pigs are dependent on environmental temperature, 41° and 95°F were selected to represent cold and hot conditions for comparison with the control treatment at 68° and 600 cc/min flow rate.

Forty-two barrows, approximately 10-weeks old and averaging 51 lb, were assigned to two replications of each of six treatments, plus control, using 3 pigs/pen. The animals were moved to the environmental laboratory's temperature-controlled rooms initially set at treatment temperatures but with all nipple waterers set at a flow rate of 600 cc/min. Following 1-week adaptation to the facilities, treatment flow rates were imposed for 4 weeks. Pigs were individually weighed three times/week and *ad-libitum* feed and water intakes were measured each week on a pen basis.

A system was also designed to measure frequency of drinking. Each water line was wrapped for a distance of 6 in with heat tape operating at about 95°F. A thermocouple was inserted in the water line to monitor water temperature downstream from the heat tape, and temperatures were scanned on a 10-sec interval. Water from the individual pen storage tank reduced the temperature of the water sensed by the thermocouple when drinking occurred and defined a drinking event. Total duration of drinking was obtained by dividing the total water consumed in each pen by the respective calibrated water flow rate for that pen.

Trial II. Results from Trial I indicated that flow rate significantly affected growth. Therefore, a second experiment was designed to establish a better functional relationship between water flow rate and animal performance at an elevated air temperature. Treatment flow rates of 100, 350, 600, 850, and 1,100 cc/min were obtained, using the same techniques as in Trial I, with gravity supply tanks providing water for individual pens. Two waterers were provided in each pen of eight pigs. No measures of frequency of drinking were made. The 4-week trial was conducted under commercial nursery conditions maintained at 86°F with eight pigs/pen, and each treatment was replicated three times. A total of 120 crossbred pigs, averaging 15 lb, were weaned and moved to pens in the nursery at 4½ weeks of age. Pigs were assigned to pens by weight to minimize weight variation within each pen. Treatments were then randomly assigned to pens so that the average initial weights of each treatment were equal. Feed and water were provided *ad libitum*, and feed, water, and animal weights were recorded on a weekly basis.

Trial III. Trials I and II had contrasting results, indicating that some factor or factors were interacting with water flow rate to affect animal growth rate. Factors that differed between trials included room temperature (86 vs 95°F), pen wall design (open wire mesh vs solid-wall enclosures), and slightly heated drinking water as a result of drinking frequency measuring systems. Therefore, the third experiment was designed to evaluate environmental temperature (41° and 68°), pen wall design (open mesh and solid sides), and the effect of heated water, evaluated only at 41°.

A total of 72 pigs, averaging 16 lb, were assigned, 4 pigs/pen, to three replications of six treatments: 68°F and pens with solid side walls or open mesh walls; 41° and pens with solid side walls and heated water or unheated water; 41° and pens with open mesh walls and heated water or unheated water. All pens were identical in construction to those used in Trial I except for the side walls. Wire mesh (9 gage wire with 4-in x 4-in openings) was used to replace the solid side panels for the open mesh treatment, and 1-ft space was provided around each open mesh pen. Heated water was obtained by wrapping heat tape and insulation around appropriate supply tanks and water lines, and water temperature was maintained near 86°. Animals were moved to the environmental laboratory and assigned to respective treatments upon weaning at approximately 4½ weeks of age. Treatment conditions were maintained for 6 weeks following a 1-week adaptation period. Individual animals were weighed three times/week with pen feed and water consumption recorded on a weekly basis.

Results

Trial I. Water flow rate and environmental temperature affected water consumption and drinking events as shown in Table 1. The highest flow rate (1,100 cc/min) was observed to be more than the pigs could physically accommodate; therefore, the greater water use included much wasted water. Water splashing on the pig served to increase heat loss by evaporation, which served as a beneficial factor at 95°F but as an adverse factor at 41°. This interaction of flow rate and temperature was partially the cause of the increase in growth rate with increased flow rate at 95° and the decrease in growth rate with increased flow rate at 41°.

Time spent drinking decreased as flow rate increased and temperature decreased. While pigs at the low-flow rate

[1]Nienaber and Hahn are agricultural engineers, Agricultural Engineering Unit, MARC.

(100 cc/min) spent approximately 30 min drinking each day at 41° and 95°F, pigs with the medium- and high-flow rates spent almost twice as much time drinking at 95° as pigs at 41°.

Blood samples were collected weekly to assure that dehydration of the animals was not occurring (Table 1). Temperature had an effect on hematocrit; however, water flow rate within each temperature did not have an effect, indicating the pigs were not unduly stressed by restricted flow rate.

Trial II. Results from Trial II showed no effects of water flow rate on growth rate, feed intake, or feed conversion of animals even though water consumption decreased with water flow rate. Results of the average performance over the 4-week trial are shown in Table 2. Drinking time, as calculated from the total water consumption and measured flow rates, was approximately constant (3.5 to 5.6 min/pig/day) over the range of 350 to 1,100 cc/min. Pigs with 100 cc/min waterers spent an average of 16.6 min/day drinking.

Trial III. Results of heating water and pen wall construction treatments at 41°F are shown in Table 3. Heated water caused an increase in growth rate at 41°, with a resultant slightly improved feed conversion. There was no effect of pen walls or any interaction of water temperature and wall construction on growth or feed and water intakes.

Results of room air temperature and pen wall construction treatments are shown in Table 4. Growth at 41°F was lower than at 68°, but there was no effect of pen wall or interactions of pen wall and temperature on growth. Air temperature and pen walls had no effect on either water or feed intake, although the latter was increased slightly at 41°, which resulted in a poorer feed conversion.

Nipple water flow rate in the range of 100 to 1,100 cc/min is not a significant factor affecting the performance of weanling pigs (4 to 8 weeks of age) at 86°F as evidenced by Trial II. Pigs were able to meet their needs by increasing the amount of time spent drinking from 3.5 to 16.6 min/pig/day and, possibly, by wasting less water. Water consumption decreased with decreasing flow rate while feed intake and growth remained unaffected.

There were beneficial effects of heating water (in a 41°F environment) shown in Trial III where the pigs with heated water grew at a higher rate. The increase in growth rate with decreasing water flow rate seen in Trial I was probably a result of interacting effects of flow rate and heated water. Since only a small portion of the water line was heated in Trial I, the low-flow rate treatment would have provided

Table 1.—Effects of water flow rate and thermal environment on performance of pigs (per pig basis)

Treatment								
Temp.	Flow	Feed	Water	Growth	Feed conv	Events	Drink time	Hemato-crit
(°F)		(lb/day)			(lb/lb)	(drink/hr)	(min/day)	(pct)
41	100	4.9	7.2	1.88	2.62	3.23	32.6	41.4
41	600	4.5	9.8	1.71	2.64	1.83	7.4	41.7
41	1,100	4.8	10.2	1.61	2.99	1.56	4.2	41.2
68	600	4.5	11.3	1.71	2.64	2.21	8.6	39.7
95	100	1.6	6.9	.61	2.66	3.48	31.3	33.6
95	600	2.5	17.7	.85	2.92	3.36	13.4	36.4
95	1,100	2.4	23.9	1.03	2.34	2.45	9.9	34.6

Table 2.—Effects of water flow rate on performance of weanling pigs in a nursery maintained at 86°F (per pig basis)

Treatment	Feed	Water	Growth	Feed conv.	Drink time
		(lb/day)		(lb/lb)	(min/day)
100	1.1	3.5	0.63	1.70	16.6
350	1.1	4.9	.63	1.70	5.6
600	1.0	6.4	.63	1.60	3.5
850	1.2	8.2	.63	1.82	4.2
1,100	1.2	11.5	.64	1.82	3.5

Table 3.—Effect of heated water and pen walls on performance of growing pigs at 41°F

Treatment	Feed	Water	Growth	Feed conv.
		(lb/day)		(lb/lb)
Heated water/solid walls	3.0	7.1	1.27	2.38
Heated water/open walls	3.1	7.1	1.27	2.40
Unheated water/solid walls	2.8	6.6	1.15	2.45
Unheated water/open walls	3.0	7.5	1.16	2.59

Table 4.—Effect of pen walls on performance of growing pigs at 41° and 68°F

Treatment	Feed	Water	Growth	Feed conv.
		(lb/day)		(lb/lb)
41°F/Solid walls	2.8	6.6	1.15	2.45
41°F/Open walls	3.0	7.5	1.16	2.59
68°F/Solid walls	2.7	7.5	1.26	2.16
68°F/Open walls	2.6	7.7	1.24	2.10

the highest average water temperature, and since the animal demonstrated the ability to adjust to its needs by increasing time spent drinking, the low-flow rate became beneficial.

As discussed earlier, the highest flow rate was such that some splashing could not be avoided. Splashing wet the skin and would cause an increased heat loss by evaporation and possibly become a deterrent to use of the waterers. The heated portion of the water line would have had a small effect on the average water temperature at the high-flow rate, so there was no growth advantage of the heated water demonstrated for that flow rate. Whether the increased growth rates would persist through the remainder of the growing period is unanswered by these experiments; it is quite possible that the 4.5 lb gain deficit of pigs given unheated water for 6 weeks at 41°F would be compensated for by the time they reached slaughter weight. It is also possible that the approximate 3.8 lb growth deficit resulting from 41° compared with 68° air temperature might be overcome by compensatory growth.

The results of Trial I at 95°F and Trial II at 86° are somewhat contradictory. It is probable that the high-flow rate provided an advantage over the two lower flow rates (Trial I) in meeting the water requirements as well as wetting of the skin surface for increased heat dissipation through evaporation. Water intake may have been limited at the lowest flow rate, although this was not shown in the hematocrit values nor was it confirmed in Trial II. Pigs used in Trial II, however, were younger and smaller (average 14.8 lb initial weight) compared to pigs used in Trial I (average 51.4 lb initial weight); therefore, the lowest flow rate (100 cc/min) that was shown to be adequate for the smaller pigs in Trial II was probably inadequate for the larger pigs of Trial I.

Following are some conclusions that may be drawn from this study:

1. Pigs weaned at approximately 4 weeks of age are unaffected by nipple waterer flow rate over a wide range (100 to 1,100 cc/min) when housed at 86°F.

2. Pigs weaned at approximately 4 weeks of age gained at a higher rate in a 41°F environment over a 6-week period when water was heated to 86°, but growth rate was not affected by the pen wall construction.

3. Older (10-week-old) pigs housed at 95°F showed an increase in growth rate as water flow rate increased from 100 to 1,100 cc/min; however, growth rate decreased as water flow rate increased for similar pigs housed at 41°.

4. Frequency of drinking and time spent drinking increased as water flow rate decreased, and water usage increased as flow rate increased at all temperatures.

Effect of Flooring Material and Number of Pigs Per Pen on Nursery Pig Performance

Ronald N. Lindvall[1]

Introduction

Investigators have reported that as the number of pigs/pen increases and the space/pig decreases, pigs in the nursery and the growing-finishing units generally gain less. Feed/unit gain is usually affected less than average daily gain (ADG). Few studies have compared the effects of number/pen (pig density) on performance of nursery pigs, based on partly slotted floors vs totally perforated floors in the same environment. Pigs in nursery pens with totally perforated floors will usually stay cleaner than pigs in nursery pens with partly slotted floors and may suffer less of a reduction in ADG from increasing the number of pigs/pen. The purpose of this study was to determine the effect of two floor types and three number/pen treatments on performance of nursery pigs. A study on the extent of decreased growth rate from increased number/pen can help give some guidelines for the maximum use of nursery facilities and the optimum building efficiency.

Procedure

Four hundred nursery pigs were tested in a nursery building in late summer. The pigs were farrowed from English Large White, Yorkshire, Swedish Landrace, and Chester White sows over a 7-week period. Approximately one-half of the pigs were crossbred and one-half were straightbred.

All pigs were weaned at 28 to 34 days of age and held for 5 days in their assigned nursery pens before the study was initiated. Pigs were assigned to treatments each week as they were weaned during the 7-week weaning period in a manner designed to balance initial average weight across all treatments. There were eight pens of 8 pigs (2.7 ft^2/pig), six pens of 12 pigs (1.8 ft^2/pig), and four pens of 16 pigs (1.3 ft^2/pig) on each of the two floor types.

Each pen was 3 x 8 ft and had one nipple waterer and a 28- x 11-in, five-hole nursery self-feeder. A freshwater-flushing system was used to remove the waste material from under both types of flooring twice daily. The pigs on the two floor types were in adjacent rooms (each 19 x 36 ft) that had the same ventilation system and were kept at the same temperature (ranging from 66° to 73°F).

The pen arrangement and design were the same in both rooms and consisted of a central alleyway and open penning. The expanded metal flooring was 9-gage, ¾-in, flattened, electrogalvanized, expanded metal running under the entire pen. This floor was 12 in above the central alleyway and approximately 30 in above the flushing gutter. The partly slotted floors were level with the alleyway and were divided into three parts: 2 ft of plastic slats (5-in wide with ½-in space) at the front of the pen, 3 ft of solid concrete in the middle, and 3 ft of the same type plastic slats at the rear of the pen.

An 18-percent protein corn-soybean diet was fed *ad libitum* throughout the study; it contained 10 percent oats, 5 percent whey, ASP 250, and vitamin and mineral supplements. Pig weights were recorded 5 days after weaning at the beginning of the study and again after 2, 4, and 5 weeks. Feed consumption by pen was recorded at each of these intervals. The analyses were completed for the 2-week first period, the 2-week second period, the 1-week third period, and the 5-week overall period.

Results

Table 1 contains the raw data means and standard deviations for pig weight, ADG, and feed efficiency for all pigs. Pigs on all treatments appeared healthy, and only one pig was removed from the study because of sickness. Our observations indicated that the pigs on the partial slats were dirtier than those on the expanded metal, but this contamination had no apparent effect on performance in this study. The pigs in pens of 16 were very crowded, especially in P3.

Table 2 presents the means for ADG and feed efficiency for each floor type, number/pen, sex, and the linear regression on initial weight for each period. The ADG of pigs on partial slats and expanded metal floors was similar in each weigh period. There were no significant interactions between floor type and number/pen; hence, increasing the number of pigs/pen reduced ADG in each period equally on both types of flooring. The effects of number/pen were significantly different in all periods and more pronounced in successive periods. Number/pen accounted for 2, 11, and 15 percent of the total variation in ADG in the three consecutive periods. Although ADG decreased as number/pen increased, the difference was less pronounced between pigs in pens of eight and pigs in pens of 12 (8 pct) than it was between pigs in pens of 12 and pigs in pens of 16 (14 pct); the reductions were 0.08 and 0.13 lb/day, respectively. Feed/unit of gain was affected less by number/pen than was ADG because pigs in more crowded pens consumed less feed. This study indicated an important effect on ADG caused by the number of pigs/pen in equal size pens; however, ADG of the pigs was not affected by floor type of expanded metal or partial slats when the other aspects of their environment were standardized.

[1]Lindvall is the swine operations manager, MARC.

Table 1.—Raw data means and standard deviations for pig weight, average daily gain, and feed/gain

Trait	Number	Mean	Standard deviation
	Pigs	(lb)	
Weight, initial[1]	399	18.4	3.3
Weight, 2 weeks	399	27.6	5.4
Weight, 4 weeks	399	42.7	7.8
Weight, 5 weeks	372	52.2	8.6
Avg. daily gain P1[2]	399	.65	.23
Avg. daily gain P2	399	1.08	.27
Avg. daily gain P3	372	1.29	.35
Avg. daily gain PT	399	.95	.19
	Pens		
Feed/gain P1	35	1.73	.21
Feed/gain P2	35	1.97	.13
Feed/gain P3	31	2.16	.35
Feed/gain PT	31	1.94	.10

[1]Average initial age was 36 days.
[2]P1 = first period, 2 weeks; P2 = second period, 2 weeks; P3 = third period, 1 week; PT = total periods, 5 weeks.

Table 2.—Means for average daily gain and feed efficiency

Item	Period 1 (2 weeks)	Period 2 (2 weeks)	Period 3 (1 week)	Period T (5 weeks)
	(lb/day)			
Average daily gain				
Flooring material:				
Partial slats	0.66	1.09	1.27	0.94
Expanded metal	.63	1.08	1.29	.92
Number/pen:	1**	1**	1**	1**
8/pen (2.7ft^2/pig)	.70	1.18	1.47	1.03
12/pen (1.8 ft^2/pig)	.59	1.16	1.29	.95
16/pen (1.3 ft^2/pig)	.63	.93	1.08	.82
Sex:				
Barrows	.64	1.10	1.28	.94
Gilts	.65	1.07	1.28	.93
Linear regression:				
Initial weight	.025	.027	.077	.029
	(feed/gain)			
Feed efficiency				
Flooring material:				
Partial slats	1.73	1.97	2.21	1.94
Expanded metal	1.72	2.01	2.13	1.95
Number/pen:				
8/pen (2.7 ft^2/pig)	1.74	1.95	2.10	1.93
12/pen (1.8 ft^2/pig)	1.75	1.91	2.16	1.91
16/pen (1.3 ft^2/pig)	1.68	2.11	2.25	1.99

[1]**P>0.01.

Effects of Environmental Temperature on Performance of Growing-Finishing Swine

John A. Nienaber and G. LeRoy Hahn[1]

Introduction

Numerous experiments have been conducted to determine the optimum environmental temperature required for swine production. To study the effects of heat stress or cold stress on performance of swine, we need to know the greatest potential possible with optimum conditions. Results from experiments conducted in California nearly 30 years ago have shown that the optimum environmental temperature shifts downward as the animal grows. These data have provided the basis for much of the current design criteria for swine housing as well as benchmarks for comparing animal performance. Each of the conditions used in the California study were imposed on animals for a relatively short time (2 weeks), and measurements of growth rate may have reflected transient conditions more than steady-state, constant temperature conditions.

Recent studies at this location and others have shown that swine are capable of compensating for stress by gaining weight at a higher than normal rate when the stress is removed. Elevated environmental temperature has been demonstrated as a stressor from which swine can recover, within limits. Therefore, this study was designed to evaluate the effects of environmental temperature on performance of swine and to identify the thermal environment or range of environmental temperatures most conducive to production of growing-finishing swine.

Procedure

Sixty crossbred gilts were randomly assigned (2 pigs/pen) to one of six environmental temperatures (41°, 50°, 59°, 68°, 77°, and 86°F). Animals ranged in weight from 84 to 136 lb and were fed until the pen of pigs averaged 187 lb. Animals were given feed and water *ad libitum* with a standard growing-finishing ration containing 16 percent protein used throughout the experiment. Feed intake and animal weight measurements were made each week. When the pen averaged 187 lb, both pigs were taken to slaughter. Each carcass was divided in half when chilled and the left half was separated into fat and lean tissue and bone.

Results

Initial weight, final weight, and performance of the growing-finishing swine as affected by environmental temperature are given in Table 1. Performance parameters of feed intake, average daily gain, and feed conversion are also shown in Figure 1. Feed intake decreased linearly from 41° to 68°F at a rate of 0.028 lb/day/°F and then dropped to 86° at a rate of 0.091 lb/day/°F. Heat production data presented in Figure 2 show that heat production decreased as temperature increased and body weight decreased. Heat production also decreased with decreased feed intake. Average daily gain increased slightly from 41° to 68° at a rate of 0.005 lb/day/°F, but dropped from 68° to 86° at a rate of 0.037 lb/day/°F. These responses resulted in the best feed conversion (3.11 lb/lb) at 68°; however, only small differences were noted from 59° to 77° in feed conversion (3.28 and 3.17 lb/lb, respectively).

Measurements on carcass tissue are given in Table 2, and percentages of lean and fat tissues based on the liveweight of animals at slaughter are shown in Figure 3. As indicated, the greatest fat content and least lean content coincide at 59°F; however, there is little difference between 50°, 59°, and 68° treatments in each of the lean and fat components. Gut fill and cooler shrink were lowest and highest, respectively, for the 86° group of pigs (Table 2). Gut fill at 86° (5.4 pct) was one-half of the average for all the other treatments (10.8 pct). Since the animals' daily feed consumption was much lower, this was as expected. Cooler shrink for the 86° group (3.7 pct) was over twice as great as the average of the other five treatments (1.7 pct), which was probably due to less fat covering the surface of the carcass and greater evaporation occurring from the lean tissue of the 86° group.

In summary, these results indicate the importance of avoiding both low and high temperatures to obtain optimum performance of animals. The results also provide a basis for estimating the effects of subjecting animals to both low and high temperatures. A producer who does not provide heating for growing-finishing animals may see small effects in growth and carcass quality but can expect an increase in feed intake and a decrease in feed conversion. Exposure of swine for extended periods at temperatures above 77°F will cause significant reductions in feed intake and growth; however, carcass quality should improve at 86° with a decrease in fat content, an increase in lean content, and decrease in gut fill.

This set of data provide a basis for evaluation of existing swine growth simulation models as well as indicating the optimum range of environmental temperatures. Since the thermal environment is seldom completely controlled as in this experiment, however, additional research into cycling thermal conditions is needed, especially where stressful (high or low) temperatures are encountered in the cycle. For example, during periods of high temperatures, it may be possible to achieve near optimal performance of swine by providing cooling only at night when climatic conditions are best. At low temperatures, radiant heating during periods of inactivity may provide all the benefits of space heating on a continuous basis. The application of computer technology to control the thermal environment requires a basis for evaluating the alternatives. Controlled environment experiments like the one recently completed provide that basis.

Table 1.—Performance of growing-finishing swine as affected by environmental temperatures

Treatment	Initial wt	No. pigs	ADG	Feed	Conv.	Final wt
(°F)	(lb)		-------- (lb/day) -------		(lb/lb)	(lb)
41 ----------	96.8	9	1.50	5.75	3.84	189.8
50 ----------	96.1	10	1.56	5.51	3.52	192.9
59 ----------	96.3	10	1.60	5.25	3.28	195.6
68 ----------	95.9	10	1.63	5.07	3.11	198.4
77 ----------	96.1	10	1.33	4.21	3.17	188.1
86 ----------	95.5	10	.96	3.44	3.59	181.9

[1]Nienaber and Hahn are agricultural engineers, Agricultural Engineering Unit, MARC.

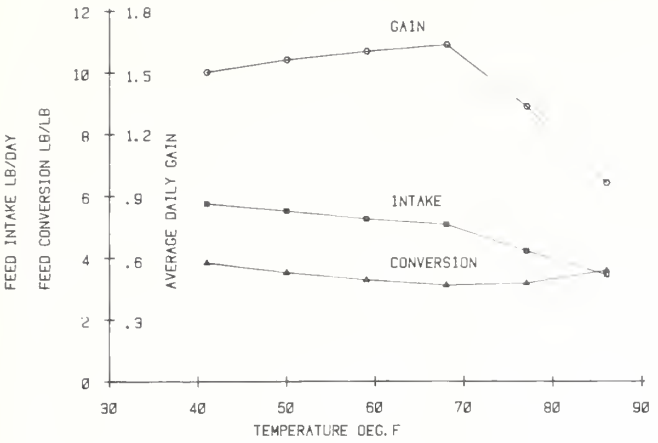

Figure 1—Average daily gain, feed intake, and feed conversion of growing-finishing swine as affected by environmental temperature.

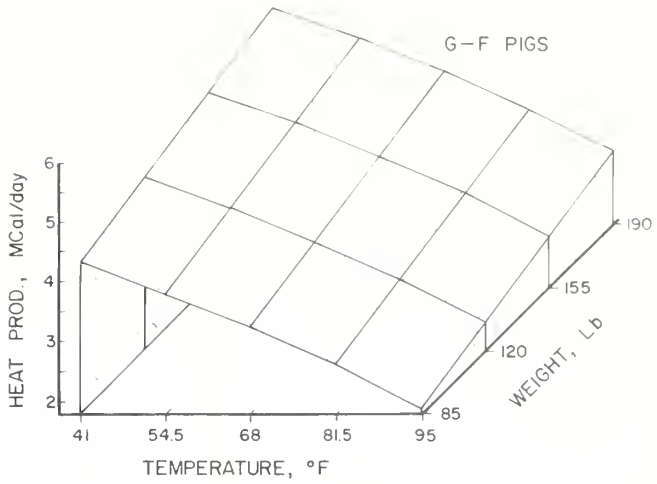

Figure 2—Heat production of *ad libitum* fed, growing-finishing swine as affected by environmental temperature and body weight.

Table 2.—Carcass measurements from swine reared at 6 environmental temperatures

Measurement	Environmental temperature, °F					
	41	50	59	68	77	86
Liveweight ----------lb---	190.0	192.9	195.3	198.4	188.1	181.9
Gut fill ----------percent---	10.4	11.1	10.3	11.8	10.6	5.4
Cooler shrink ----------percent---	1.5	1.7	1.6	1.4	2.1	3.7
Lean ----------percent---	42.1	40.4	40.1	40.8	42.1	46.9
Fat ----------percent---	8.2	9.1	9.8	9.2	7.7	5.7
Bone----------percent---	9.1	8.9	9.1	9.4	9.5	10.4
Head, feet, and hide----------percent---	17.4	17.4	17.4	16.2	17.6	17.1
Blood, organs, and intestines----------percent---	11.3	11.4	11.7	11.2	10.4	10.8

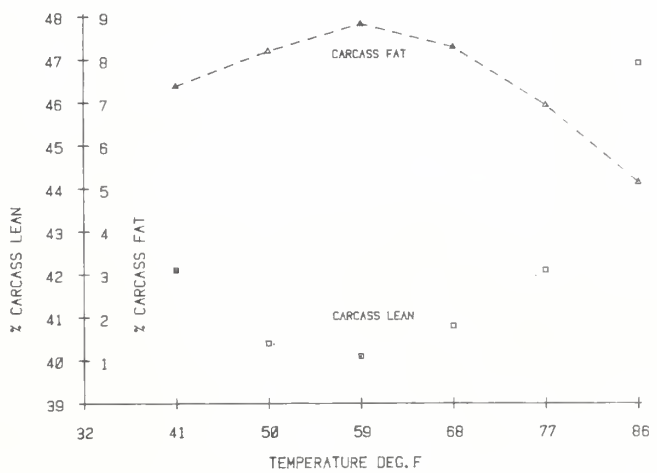

Figure 3—Carcass composition of 190-lb swine reared at temperatures of 41 to 86°F, percent slaughter weight.

Methane from Swine Manure

Andrew G. Hashimoto[1]

Introduction

The digestibility of swine manure is much higher than beef or dairy manure; however, about four times higher methane production rates have been achieved by fermenting cattle manure compared to swine manure. The main reason for the higher methane production rates from cattle manure was the higher loading rates used for the cattle manure fermentations. Optimum design loading rates for swine fermentors were reported to be 0.25 lb VS/ft^3-day at 93°F. These loading rates were for mesophilic fermentations and were one-fourth to one-fifth the loading rate achieved for cattle manure fermented at thermophilic temperatures. We showed that, for beef-cattle manure, much higher loading rates could be used at thermophilic (130°) temperatures compared to mesophilic (93°) temperatures; however, others have shown that, for swine manure at the same loading rate and hydraulic retention time (HRT), mesophilic fermentations produced about 25 percent more methane than thermophilic fermentations.

This study was initiated to study the effects of temperature (93° and 130°F), influent volatile solids (VS) concentration, and HRT on methane production from swine manure.

Procedure

Batch and daily-fed (once/day) fermentors were used in this study. The batch fermentors were used to determine the ultimate methane yield of the swine manure, and the daily-fed fermentors were used to evaluate the effects of temperature, influent concentration, and HRT on methane production. The batch and daily-fed fermentors were 4-qt aspirator bottles with working volumes of 3 qt. The fermentors were mixed using a platform shaker rotating at 140 revolutions/min. The fermentors were housed in a constant-temperature chamber, and temperatures were controlled within 2°F using heating tapes wrapped around the fermentors.

Swine manure (feces and urine) was collected from pigs (weighing 175 to 200 lb) confined in metabolism stalls and fed a ration consisting of 82.1-percent corn (No. 2 yellow dent), 14.0-percent soybean meal, 2.4-percent dicalcium phosphate, 0.5-percent ground limestone, 0.4-percent iodized salt, 0.4-percent vitamin premix, and 0.4-percent trace minerals. This ration contained approximately 14-percent protein, 0.8-percent calcium, 0.8-percent phosphorus, and metabolizable energy of 1.4 Mcal/lb. Antibiotics were not used in the ration.

One-day-old manure (about 14-pct dry matter) was placed in plastic bags (about 12 lb/bag) and frozen at −4°F. Periodically, a bag of manure was removed from the freezer, allowed to thaw overnight in a refrigerator, and appropriate amounts of manure were weighed into polyethylene bottles. The bottles were then refrozen until used. Before use, the bottles were placed in a refrigerator to thaw overnight, and the manure was diluted with hot tap water to the desired volume and VS concentration.

Eight batch fermentors were started by placing 1 qt of inoculum from stable fermentors operating at 93° and 130°F, and 1 qt of mineral solution in each fermentor. Four fermentors were maintained at 130° and four at 93° for 21 days to allow temperature equilibration and use of substrate contained in the inoculum. Two of the fermentors at each temperature were each fed manure containing 1 oz VS in 1 qt over a period of 7 days. The other two fermentors at each temperature were each fed 1 qt of the mineral solution and served as controls. These batch fermentors were operated for 146 days, during which gas volume and composition (methane and carbon dioxide) were measured periodically. At the end of the study, the total volume of methane produced, including the methane present in the fermentor head space, was calculated. Methane yield was calculated by subtracting the total methane produced in the control from that produced in the manure fermentors and dividing by 1 oz VS.

The daily-fed fermentors (two fermentors at 93°F and two at 130°) were started by placing 3 qt of acclimated inoculum (from beef-manure fed fermentors at 93° and 130°) in each fermentor. The fermentors were fed manure slurries containing 3.9 lb VS/ft^3 at 25-days HRT. Steady state was assumed after four volume turnovers, and methane production and effluent characteristics were analyzed for 5 consecutive days. The influent concentration was then reduced to 3.2 lb VS/ft^3 and the HRT to 15 days. The same procedure outlined above was continued until steady-state data were obtained at 10- and 5-days HRT. Only one fermentor, however, was operated at 93° and 5-days HRT because insufficient manure was available near the end of the study.

Biogas produced in the fermentors was collected in gas-impermeable bags and analyzed for gas volume, at standard temperature (32°F) and pressure (1 atmosphere), and methane concentration. The gas volumes were measured by a solution-displacement method, and the methane content was measured by gas chromatography.

Results

Methane yields for the 93°F batch fermentors were 7.8 and 8.0 ft^3 methane/lb VS fed and 7.4 ft^3 methane/lb VS fed for the 130° fermentor. The other batch fermentor at 130° developed a leak in the gas collection bag; therefore, a replicate at 130° was not obtained. Since we have previously shown that the fermentation temperature does not affect the methane yield of a given substrate, the mean methane yield was calculated to be 7.8 ft^3 methane/lb VS fed with a standard deviation of 0.3 ft^3 methane/lb VS fed.

The original experiment design called for the fermentors to receive about 3.8 lb VS/ft^3 at 25-, 15-, 10-, and 5-day HRT;

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however, stable fermentation could not be achieved by the 130°F fermentors at 25-days HRT. Therefore, the influent concentration was reduced to about 3.1 lb VS/ft^3 for the trials at 15-, 10-, and 5-days HRT.

The methane production rate from the 93°F fermentors increased until day 85, then remained fairly constant at about 1-ft^3 methane/ft^3 fermentor-day. In contrast, the methane production rate from the 130° fermentors remained fairly constant (about 0.9-ft^3/ft^3 fermentor-day) between days 28 to 76, then decreased sharply to about 0.3-ft^3 methane/ft^3 fermentor-day between days 94 to 108. The sharp drop in methane production rate began when the total volatile acids (TVA) exceeded 4,000 parts per million (ppm). The increase in TVA with time indicates fermentation instability, and TVA in excess of 4,000 ppm indicate extreme instability. The free-ammonia concentration was 410 and 170 ppm for the 130 and 93° fermentors, respectively.

Because the thermophilic fermentors were unstable, the influent concentration was reduced from 3.9 to 3.2 lb VS/ft^3. The 130°F fermentors were restarted by replacing 2 qt of slurry with 1 qt of inoculum from the 93° fermentors and 1 qt of inoculum from a thermophilic, beef-manure fermentor.

The results from this experiment showed stable fermentation at 93° and 130°F. Least-squares analysis of the data showed that the 130° fermentors produced significantly higher methane production rates; had higher concentration of ammonia, TVA, and pH; and had lower effluent VS concentrations than the 93° fermentors. The individual volatile fatty acids from the 130° fermentors were also significantly higher than from the 93° fermentors. The predominant fatty acid from the 93° fermentors was acetic acid while the predominant acids from the 130° fermentors were propionic and acetic acids.

Results of this study have shown fermentation instability at 130°F, 25-days HRT, and influent concentration of 3.9 lb VS/ft^3. No instability was noted at the same influent concentration and HRT, but a fermentation temperature of 93° was noted. At an influent concentration of 3.2 lb VS/ft^3 and HRT of 15, 10, and 5 days, however, instability was not observed at fermentation temperatures of 130° and 93°. It was unlikely that high loading rate caused the unstable fermentation because the loading rates at 3.2 lb VS/ft^3 were higher than at 3.9 lb VS/ft^3.

One probable cause for the instability at 3.9 lb VS/ft^3 was the higher free-ammonia concentration at 130°F compared to 93° (410 vs 170 ppm). It is not likely, however, that the free-ammonia concentration was the only cause of instability since comparable levels of free ammonia were experienced at 130° and 3.2 lb VS/ft^3 (580 to 300 ppm) with no apparent instability. It is probable that the high free-ammonia concentration at 130° contributed to the instability at 3.9 lb VS/ft^3 and that the thermophilic microorganisms adapted to the higher free ammonia when the influent concentration was reduced to 3.2 lb VS/ft^3 and the HRT to 15 days. Note that the thermophilic microorganisms were exposed to the high free-ammonia concentrations for over 170 days (this includes the 108 days at influent concentrating 3.9 lb VS/ft^3 and 15-days HRT).

Another factor contributing to the instability at 130°F and 3.9 lb VS/ft^3 was the higher influent concentration. We have reported that methane production rates become increasingly inhibited as the influent VS concentration increases above certain threshold concentrations. Results from this study show that inhibition begins when the influent concentration exceeds 3.1 lb VS/ft^3.

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